

Harder

Alloys of chromium, copper and nickel.

THE UNIVERSITY  
OF ILLNIOIS  
LIBRARY

1915

H21

ALLOYS OF CHROMIUM, COPPER AND NICKEL

BY

OSCAR EDWARD HARDER

B. A. University of Oklahoma, 1910

M. A. University of Oklahoma, 1911

THESIS

Submitted in Partial Fulfillment of the Requirements for the

Degree of

DOCTOR OF PHILOSOPHY

IN CHEMISTRY

IN

THE GRADUATE SCHOOL

OF THE

UNIVERSITY OF ILLINOIS

1915





UNIVERSITY OF ILLINOIS  
THE GRADUATE SCHOOL

May 15, 1955

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Oscar Edward Harder

ENTITLED ALLOYS OF CHROMIUM, COPPER AND NICKEL

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF DOCTOR OF PHILOSOPHY

D. F. McFarland  
In Charge of Major Work

W. A. Noyes  
Head of Department

Recommendation concurred in:

S. W. Parr  
W. A. Bayley  
C. G. Denick

} Committee  
on  
Final Examination



Digitized by the Internet Archive  
in 2013

[http://archive.org/details/alloysofchromium00hard\\_0](http://archive.org/details/alloysofchromium00hard_0)

1915  
Hal

## ACKNOWLEDGMENTS

In this work valuable assistance has been received from a large number of persons connected with the University of Illinois and the writer wishes to express his gratitude to those persons.

Professor D. F. McFarland has had charge of the entire investigation and has given much encouragement and assistance. Professor S. W. Parr has given many helpful suggestions. Professor H. F. Moore of the Department of Theoretical and Applied Mechanics directed the mechanical tests and criticised that part of the thesis. Mr. S. M. Hull made the copper and nickel determinations. Others to whom the writer is under obligations include Drs. Beal, Broderson and MacInnes, Messrs. Ford, Westhafer, McClelland, Rowland, Lee and Brown and Miss Scott. The writer is also under obligations to the University of Illinois for a Fellowship in Chemistry during the two years that this investigation has been in progress.



## CONTENTS

	<u>Pages</u>
I. INTRODUCTION .....	1-7
1. Purpose of Investigation .....	1
2. Historical Review .....	1
Copper-Nickel Alloys .....	1
Chromium-Copper Alloys .....	4
Chromium-Nickel Alloys .....	5
Binary Alloys .....	6
Ternary Alloys .....	7
3. Plan of Work. ....	7
II. ELECTRIC FURNACE .....	9-15
1. Requirements of Furnace .....	9
2. Early Experiments .....	9
3. Description of Parts .....	10
Magnesia Cylinders .....	10
Magnesia Crucibles .....	10
Electrodes .....	11
Resistor .....	11
4. Adjustment of the Resistance .....	12
5. Temperatures Obtainable .....	13
6. Atmosphere in Furnace .....	13
7. Conclusions .....	13
III. PREPARATION OF THE ALLOYS .....	16-24
1. Materials .....	16
2. Melting of Metals .....	16





CONTENTS  
(continued)

	<u>Pages</u>
3. Casting the Samples .....	17
4. Composition of the Alloys .....	18
5. Analysis .....	18
6. Changes in Composition .....	18
7. Alloy of 50% Cr and 50% Ni .....	20
IV. THERMAL ANALYSES AND HEAT-TREATMENTS ...	25-26
1. Difficulties of Thermal Analysis ..	25
2. Heat-Treatments .....	26
Annealing Tests .....	26
V. PHYSICAL AND MECHANICAL PROPERTIES .....	27-38
1. Color and Appearance .....	27
2. Specific Gravity .....	28
3. Brinell Hardness Number .....	32
4. Tensile Strength and Stress- Deformation Tests .....	34
Test Pieces .....	35
Testing Machine and Method of Loading .....	35
Extensometer .....	35
Calculation of Modulus of Elasticity .....	36
Reduction and Elongation .....	37
Ultimate Strength .....	38
Modulus of Elasticity .....	38
VI. RELATIVE ELECTROMOTIVE FORCES OF THE ALLOYS IN CONTACT WITH ELECTROLYTES ....	39-45
1. Purpose of Measurements .....	39





CONTENTS  
(continued)

	<u>Pages</u>
2. Experimental .....	39
3. Poggendorf Compensation Method .....	40
VII. CORROSION TESTS .....	46-72
1. Reason for tests .....	46
2. Materials .....	46
3. Methods .....	46
Solutions .....	46
Suspending the specimens .....	47
Temperature .....	47
Time .....	48
Calculations .....	48
Accuracy of the Method .....	48
4. Results .....	48
Salt Solution .....	48
Hydrochloric Acid .....	49
Sulfuric Acid .....	49
Nitric Acid .....	49
Sodium Hydroxide .....	49
Ammonium Hydroxide .....	49
Fatty Acids .....	50
Comparison of Corrosions .....	50
5. Conclusions .....	50
VIII. MICROSCOPIC EXAMINATION .....	73-77
1. General Discussion .....	73



## CONTENTS

(continued)

	<u>Pages</u>
2. Etching Reagents .....	73
Ferric Chloride and Hydrochloric Acid	73
Alkaline Potassium Tartrate .....	73
Picric and Nitric Acids .....	74
Hydrochloric Acid and Nitrophenol ....	74
Picric Acid .....	74
Sodium Picrate .....	74
Tartaric Acid .....	74
Iodine .....	74
3. Results .....	75
Voss' Conclusions .....	75
Chromium-Nickel Alloys .....	75
Copper-Nickel Alloys .....	76
Solubility of Chromium in Copper .....	76
Effect of Nickel on the Solubility of Chromium .....	76
Crystals in Nickel-rich Alloys .....	77
IX. SUMMARY AND CONCLUSIONS .....	78-80
AUTOBIOGRAPHY .....	81



## TABLES

		<u>Pages</u>
No.1	Composition of Alloys .....	22
2	Hardness, Specific Gravity, and Kind of Casting .....	29
3	Table showing the composition of the Alloys, their Modulus of Elasticity and Ultimate Tensile Strength .....	36
4	Table of Relative Electromotive Forces of the Different Alloys in Contact with 4 Normal Salt Solutions .....	44
5	Corrosion in Normal Salt Solution .....	51
6	Corrosion in Normal Hydrochloric Acid .....	54
7	Corrosion in Normal Sulfuric Acid .....	57
8	Corrosion in Normal Nitric Acid .....	60
9	Corrosion in Normal Sodium Hydroxide .....	63
10	Corrosion in Normal Ammonium Hydroxide .....	66
11	Corrosion in Fatty Acids. ....	69
12	Comparison of the Corrosions in the Different Solutions .....	70

## PLATES

Nos. 1-16 Microphotographs





## FIGURES

1. Copper-Nickel Diagram according to Victor E. Tafel.
2. Chromium-Copper Diagram according to G. Hindrichs.
3. Nickel Chromium Diagram according to G. Voss.
- 4A. Electric Furnace. Vertical Section A.
- 4B. Electric Furnace. Vertical Section B.
5. Magnesia Cylinder, Magnesia Crucible, Crucible Mould, and Graphite Electrodes.
6. General View of Electric Furnace.
7. Diagram Showing Composition of Alloys and Specific Gravities at 25°C.
8. Stress-Deformation Curve for Alloy No.14.
9. Stress-Deformation Curves for Alloys Nos.24, 25, 26, and 29.
10. Stress-Deformation Curves for Alloys Nos.33, 34, 35, 36, 37, and 38.
11. Stress-Deformation Curves for Alloys Nos.42 and 44.
12. Stress-Deformation Curves for Alloys Nos.48, 49, and 51.
13. Apparatus Used in Measuring the Relative Electromotive Forces of the Alloys in Contact with an Electrolyte.
14. Diagram Showing the Composition of the Alloys and Their Changes in Electromotive Forces in 4 Normal Salt Solution.
15. Diagram Showing Corrosion in Normal Salt Solution.
16. Diagram Showing Corrosion in Normal Hydrochloric Acid.
17. Diagram Showing Corrosion in Normal Sulfuric Acid.
18. Diagram Showing Corrosion in Normal Nitric Acid.
19. Diagram Showing Corrosion in Normal Sodium Hydroxide.
20. Diagram Showing Corrosion in Normal Ammonium Hydroxide.
21. Diagram Showing Corrosion in Fatty Acids.





# ALLOYS OF CHROMIUM, COPPER AND NICKEL

## I. Introduction

1. Purpose of Investigation. The acid resisting properties of the alloy developed by Professor Parr \* seem to justify a

---

\* S. W. Parr. Orig. Com. 8th Inter. Congr. Appl. Chem., 2, (1912) p. 209.

---

detailed and systematic study of the alloys of the more important constituents, viz. chromium, copper and nickel. Also in order to study the very complex alloy, it seems advisable to begin with the alloys containing only two metals, then to proceed to those of three metals and finally to extend the investigation to those containing four or more metals. In the present work it is intended to study first the binary alloys of copper-nickel, copper-chromium and chromium-nickel, and then the ternary alloys of chromium-copper-nickel.

2. Historical Review. In this review it is intended to give only the more important results of previous investigations and references to the original publications.

Copper-Nickel Alloys:- Christofle and Bouilhet \* prepared

---

\* Christofle and Bouilhet. Bull. Soc. Chem., XXVI., (1876) p. 419. Compt. rend. LXXXIII., (1876) p. 29.

---

alloys containing 50 per cent of copper and 50 per cent of nickel, and 85 per cent of copper and 15 per cent of nickel and observed some of their properties.

In 1896 H. Gautier \* made a more extensive study of these

---

\* H. Gautier. Compt. rend. CXXIII., (1896) p. 172.

---



alloys. He determined their freezing-points and concluded that they formed a definite chemical compound having the formula  $\text{CuNi}$  which melted at  $1340^{\circ}\text{C}$ . The original paper was presented by H. Moissan.

Heycock and Neville \* in their work on the "Complete

---

\* Heycock and Neville. Philos. Trans., 189A (1897) p. 25.

---

Freezing-point Curves of Binary Alloys containing Silver or Copper together with Another Metal" tried the effect of the addition of small amounts of nickel upon the freezing-point of copper and found that the freezing-point was raised from  $1080$  to  $1110^{\circ}\text{C}$ . by the addition of 4.5 per cent of nickel.

Kurnakoff and Schemtschny \* prepared alloys from electro-

---

\* Kurnakoff and Schemtschny. Z. anorg. Chem., 54, (1907) p. 149.

---

lytic copper and nickel, determined their freezing-points, plotted the freezing-point curve, studied the structure of the different specimens and pointed out certain similarities to the alloys of iron-copper, cobalt-copper, and copper-nickel. They took  $1484^{\circ}\text{C}$ . as the melting point of nickel which is now known to be too high.

Guertler and Tammann \* in their investigation of the

---

\* Guertler and Tammann. Z. anorg. Chem., 52, (1907) p.25.

---

alloys of copper and nickel showed that there was no break in either the liquidus or solidus curves. This showed that these alloys do not form a definite chemical compound as had been claimed by H. Gautier. They also made both magnetic and microscopic examinations and showed the effect of heat on the magnetic proper-





ties as well as the effect of the rate of cooling on the grain and crystal size.

The following year (1908) Victor E. Tafel \* published

---

\* Victor E. Tafel. Metallurgie, 5, (1908) p. 348.

---

the results of his studies of the constitution of the binary system copper-nickel. His work seems to be the best that has been published and for convenience his results are shown diagrammatically in Fig. 1. He obtained higher values for both the liquidus and the solidus curves than did Guertler and Tammann, but that may be attributed to the fact that they used nickel which contained a considerable amount of impurities (0.47% Fe, 1.86% Co.) which would lower the freezing-points.

E. Vigouroux \*, using pure metals, especially free from

---

\* E. Vigouroux. Compt. rend. 159, (1909) p. 1378.

---

cobalt, prepared a series of copper-nickel alloys, but he was unable to detect any indication of definite chemical compounds by chemical investigation or by a study of the electromotive forces in the cells  $\text{Ni} \text{---} \frac{\text{N}}{1}$ ,  $\text{NiSO}_4 \text{---} \text{CuNi}$  alloy and  $\text{Cu} \text{---} \frac{\text{N}}{1}$ ,  $\text{NiSO}_4 \text{---} \text{CuNi}$  alloy. His results by this method agree with those obtained by the cooling-curve method.

David H. Browne \* secured U.S. patent 934,278 (Sept. 14,

---

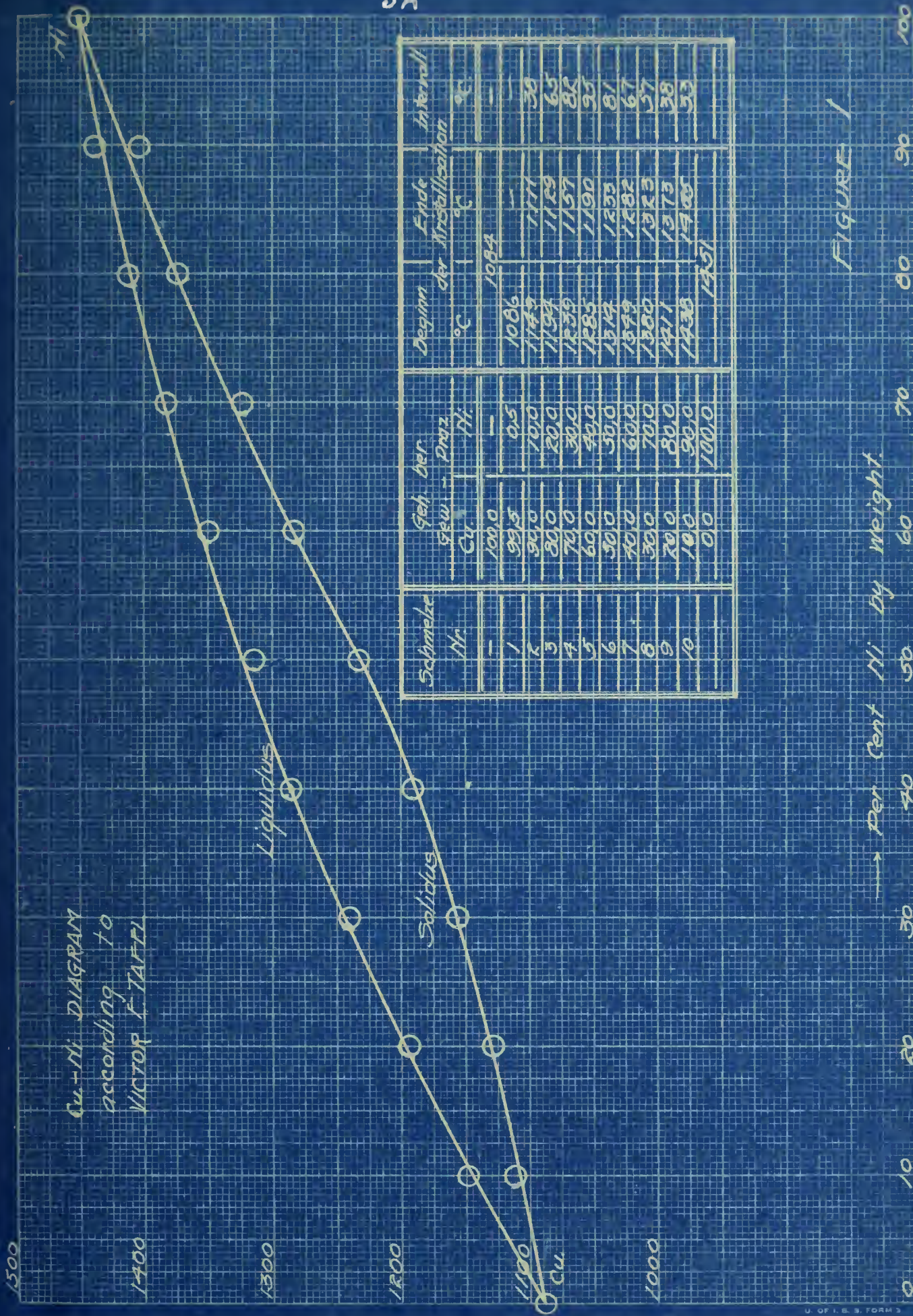
\* David H. Browne. C.A., 4, (1910) p. 41.

---

1910) for the manufacture of nickel and copper-nickel alloys by electrically fusing compounds of the metals as sulphide matte with lime ( $\text{CaO}$ ) forming calcium sulfide ( $\text{CaS}$ ) sulfur dioxide ( $\text{SO}_2$ ) and







Schmelze Nr.	Geh. der gew. - Proz.		Beginn der Kristallisation		Intervall
	Cu	Ni	°C	°C	°C
-	100.0	-	1084	-	-
1	99.5	0.5	1086	-	-
2	90.0	10.0	1149	1111	38
3	80.0	20.0	1194	1129	65
4	70.0	30.0	1239	1157	82
5	60.0	40.0	1285	1190	95
6	50.0	50.0	1317	1233	84
7	40.0	60.0	1349	1282	67
8	30.0	70.0	1380	1323	57
9	20.0	80.0	1411	1373	58
10	10.0	90.0	1438	1405	53
-	0.0	100.0	1451	-	-

FIGURE 1

→ Per Cent Ni by weight

LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS



an alloy of the metals.

Chromium-Copper Alloys:- H. Moissan \* prepared an alloy

---

\* H. Moissan. Compt. rend., 119 (1894) p. 185.

H. Moissan. Compt. rend., 122 (1896) p. 1302.

---

of chromium and copper which contained about 0.5 per cent of chromium. It was more resistant to humid air than was copper and took a beautiful polish.

H. Goldschmidt \* has described an alloy of chromium and

---

\* H. Goldschmidt. Lieb. Ann., 301, (1898) p. 25.

---

copper, containing 10 per cent of chromium and having the color of copper but harder. The Goldschmidt Thermit Company, \* 90 West Street, New York, now offer for sale an alloy of chromium-copper,

---

\* Thermit Carbon-Free Metals. Pamphlet No.20, second edition p.23.

---

containing 10 per cent of chromium. The alloy is made by the aluminothermic method. This alloy will be discussed more fully under the "Preparation of Alloys".

Hamilton and Smith \* heated chromium oxide and metallic

---

\* Hamilton and Smith. Jour. Am. Chem. Soc., 23, (1901) p. 151.

---

copper in a carbon crucible and in the presence of carbon, by which process they obtained an alloy of gray-red color and of a hardness which placed it next to the alloys containing tungsten and molybdenum. The alloy gave the analysis: 88.18% Cu, 3.22% Cr, 1.35% Fe, 2.38% C, and 4.13% gangue. The alloy had a specific gravity of 8.3.



Binet de Jassonnix \* stated that chromium dissolved in

---

\* Binet de Jassonnix. Compt. rend., 144, (1907) p.915.

---

copper to the extent of about 1.6 per cent, but that on cooling the chromium separated in a very finely divided condition.

G. Hindrichs \* made a more extensive study of the alloys

---

\* G. Hindrichs. Z. anorg. Chem., 59, (1908) p. 414.

---

of chromium and copper. He decided that the freezing-point of copper was lowered about 8 degrees by the addition of about 0.5 per cent of chromium and that the maximum solubility of chromium in copper was about 0.5 per cent. He, likewise, found that the freezing-point of chromium was lowered from 1550 to about 1470°C. by the addition of about 5. per cent of copper and considered that the maximum solubility of copper in chromium was not over 5. per cent. From his researches it seems that there are two eutectic points in the chromium-copper freezing-point curve. His chromium-copper diagram has been reproduced in Fig. 2. He pointed out some of the difficulties in working with chromium or chromium-copper alloys. Chromium remains viscous after melting, attacks the crucibles, insulating tubes, etc., and has a strong tendency to oxidize. He was not able to get chromium and copper to separate into two well defined layers.

From the above it may be seen that the different investigators have placed the solubility of chromium in copper at 0.5, 1.6, 3.22, and 10 per cents.

Chromium-Nickel Alloys:- G. Voss \* has investigated the







LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS



---

\* G. Voss. Z. anorg. Chem., 57, (1908) p. 34.

---

alloys of chromium and nickel. His chromium-nickel diagram has been reproduced in Fig. 3. At the time he published his paper he stated that he was unable to find any published literature on the subject and at the present time he seems to be the only one who has published his researches. However, there have been extensive researches in the development of such alloys as "Nichrome", but these have been conducted in commercial laboratories and the results have not been published. Voss showed that the system consists of two series of solid solutions with a minimum freezing-point of about 42 per cent of nickel. From a microscopic examination he concluded that the point represented a true eutectic, although he was not able to demonstrate the presence of a eutectic structure on either side of this point. He assumed the presence of a solution gap (Mischungslücke). On the other hand Guertler \*

---

\* Guertler. Metallographie. Vol.I. Part 1 (1912) p. 209.

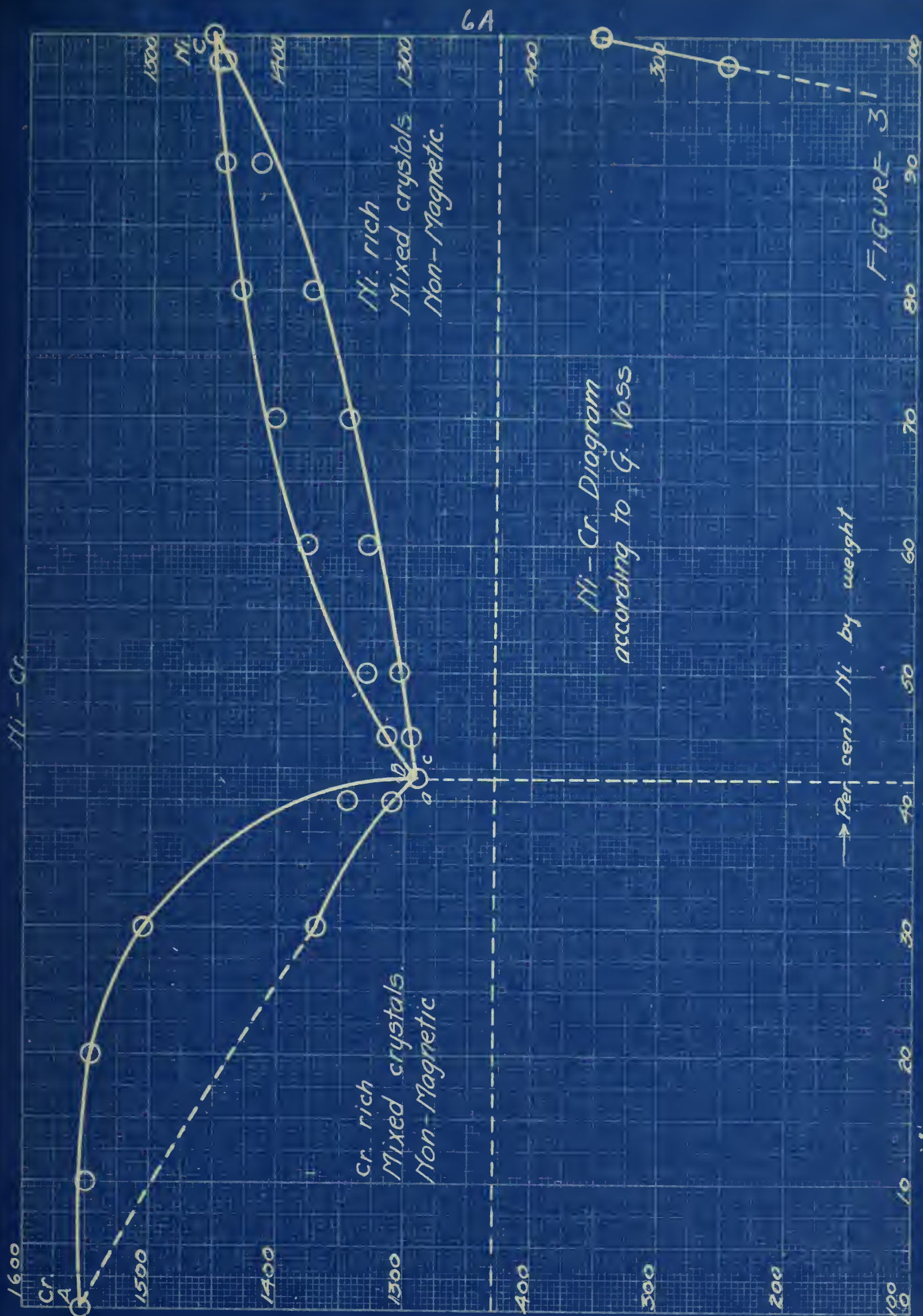
---

concluded that the structure represented a condition of unstable equilibrium which he termed a psuedoeutectic produced by the extreme viscosity of the chromium.

To summarize, the binary alloys belong to three different classes: copper-nickel representing those which have continuous freezing-point curves, chromium-nickel representing those which have two series of solid solutions and a minimum freezing-point, and chromium-copper those which have two eutectic points. The freezing-point curves for copper-nickel and for chromium-nickel seem to be pretty well established but the exact location of a large part







OF THE  
UNIVERSITY OF ILLINOIS

of the freezing-point curve for chromium-copper is unknown.

Ternary Alloys:- The ternary alloys of chromium-copper-nickel have not been described, so far as is known to the writer, but four ternary systems which are somewhat closely related have been reported: Copper-nickel-zinc by Victor E. Tafel,(1); copper-iron-nickel by R. Vogel,(2); copper-manganese-nickel by M. Parravano,(3); and cobalt-copper-nickel by Wählert,(4).

(1) Victor E. Tafel, *Metallurgie*, 5, (1908) p. 413.

(2) R. Vogel. *Z. anorg. Chem.*, 67, (1910) p. 1.

(3) N. Parravano. *Inter. Z. Metallographie*, 4, (1913) p. 171.

(4) Wählert. *Oester. Z. Berg. Hüttenw.*, 62, (1914) pp.341-6, 357-61, 374-8, 392-5, and 406-10. *C.A.*, 8, (1914) p.3549.

3. Plan of work. It was originally intended that this investigation should include the following:

1. The construction of an electric furnace which would give a temperature sufficiently high to melt chromium.

2. The preparation of samples of both the binary and ternary alloys which would represent all of the possible combinations with variations of 10 per cent of the different constituents.

3. Thermal analyses and heat treatments.

4. Physical and mechanical examinations which would include color, appearance, specific gravity, hardness, tensile strength, reduction, elongation, and modulus of elasticity.

5. Measurements of the relative electromotive forces of the alloys in contact with salt solutions.

6. Corrosion tests in salt solution, in hydrochloric acid, in sulfuric acid, in nitric acid, in sodium hydroxide, in ammonium hydroxide and in fatty acids.





## 7. Microscopic examination.

The program has been carried out in the main with the exception of the thermal analysis and heat treatment. Considerable time and effort have been expended on the attempt to work out suitable means for the former, but the experimental difficulties seemed insurmountable so far as the present work is concerned. It was thought best also to postpone the study of heat treatment until the equilibrium diagram could be obtained.





## II. ELECTRIC FURNACE.

1. Requirements of Furnace. For the proposed work it was necessary to have a furnace which would give temperatures well above the melting point of chromium ( $1520^{\circ}\text{C}.$ ) and which would maintain these temperatures for any period of time. It was desirable to have the crucibles made of some material which would not be attacked by the metals chromium, copper, nickel, or their oxides, or by any cover which might be used to protect the metals from oxidation, and of such size that they would contain a charge of 100 grams or more. It was further desirable to be able to maintain a neutral or reducing atmosphere in the furnace during the heating and cooling. Other limitations required that the furnace should operate on a 110 volt circuit without a transformer and that it should not require a current of more than 30 amperes.

2. Early Experiments. After a brief examination of the numerous descriptions of electric furnaces which had been published, it was decided that the one described by Calhane and Bard \*

---

\* Calhane and Bard. Met. and Chem. Eng. 10 (1912) p. 461.

---

came the nearest to meeting all of the requirements and a modified form of that furnace was used to begin the experimental work. A general view of the experimental furnace is shown in Fig.6. The alundum cylinder used in this furnace was later replaced by one of magnesia (See Fig.5) because it was found that the alundum became a rather good conductor of electricity when heated to about  $1300^{\circ}\text{C}$  and, moreover, it cracked badly on rapid heating. The alundum crucible and the alundum blocks for supporting the crucible



were also replaced by magnesia parts. Otherwise, the experimental furnace did not differ materially from the one finally developed. A general view is shown in Fig.6, some of the parts are shown in Fig.5, and vertical sections at right angles to each other are shown in Fig.4A and Fig.4B. The parts will be described in detail below.

3. Description of Parts. The fire clay parts were made in the Ceramics Department of the University of Illinois. They have been found quite satisfactory and have required no repair up to the present time. They were made by a student and the cost of his labor at 25¢ per hour was \$6.50.

Magnesia Cylinders:- Although various refractories were tried, fused magnesia was found to be the most satisfactory material for the cylinders. This material requires special mention. It was prepared by Mr. T. D. Yensen \* of the Engineering Experiment

---

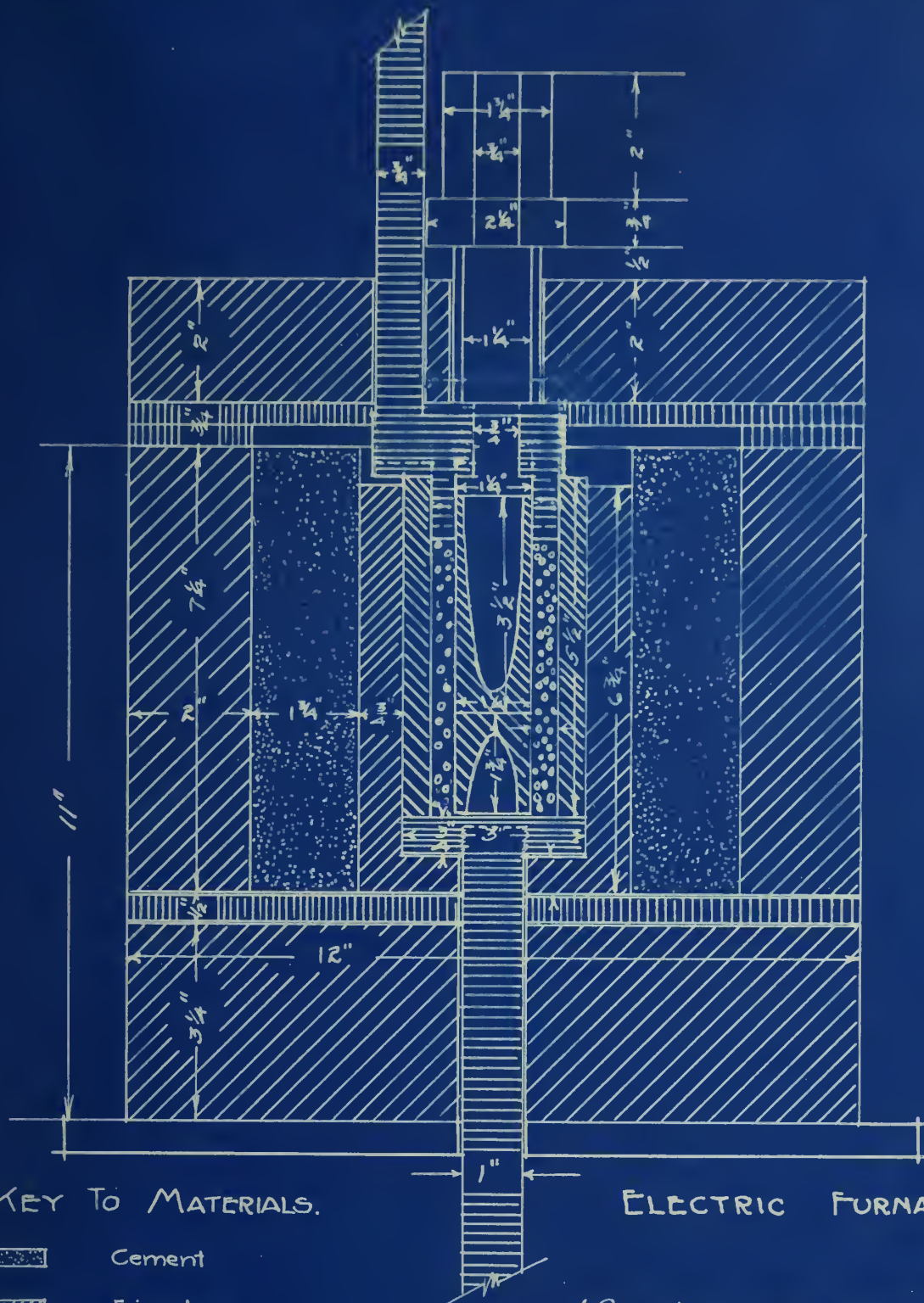
\* Yensen, Bulletin No.72, Eng. Exp. Sta., Univ. of Ill. (1914) p.49

---







Station of the University of Illinois and was made by fusing precipitated magnesium carbonate. According to Yensen, the fused magnesia contained 1 per cent  $\text{SiO}_2$ , which is a higher degree of purity than can be obtained by fusing native magnesite. The other refractories included alundum, chromite, mixtures of Portland cement and magnesia, and a mixture of fire clay and magnesia. The method used for making the magnesia cylinders, although somewhat crude, probably deserves mention. The magnesia was moistened with a suspension of 10 parts of magnesium carbonate to 100 parts of water and packed into a mould consisting of two concentric cylinders of such diameters that the distance between them gave the de-







## KEY TO MATERIALS.

-  Cement
-  Fireclay
-  Magnesite
-  Asbestos
-  Granular Carbon
-  Graphite

## ELECTRIC FURNACE

(Granular Carbon Resistance)

## VERTICAL SECTION - A.

Scale  $\frac{3}{8}$ " = One Inch

OF THE  
UNIVERSITY OF ILLINOIS

sired thickness to the magnesia cylinder. The parts of the mould which would be in contact with the magnesia were previously coated with paraffin. By heating at  $105^{\circ}\text{C}$ . in an electric oven, the paraffin was removed and at the same time the magnesia cylinder was dried and hardened so that it could be removed without danger of breaking. The dried cylinder was then placed in a Hoskins electric furnace and heated to a temperature of about  $1600^{\circ}\text{C}$ . The loss in weight due to heating was about 6.5 per cent and the shrinkage in dimensions was about 4 per cent.

Magnesia Crucibles:- The magnesia crucibles were made by packing magnesia moistened with hydrated magnesium carbonate as referred to above, into the mould shown in Fig.5. Then by applying pressure to the plunger which rested against the bottom of the crucible, the latter could be made quite compact. The core for the inside of the crucible and the small collar at the top of the crucible were then removed and the crucible forced out by means of the plunger. The mould had a slight taper which made the crucibles a little larger at the top than at the bottom and at the same time made them more easily removable from the mould. They were then dried and heated to about  $1600^{\circ}\text{C}$ . They have been quite satisfactory.

Electrodes:- The electrodes were of graphite and were of the forms shown in Figs. 5, 4A and 4B.

Resistor:- Coke, graphite and compressed carbon have been tried as resistors. In all cases the material used was in granular form and of such size that it would pass through a 10 mesh sieve and would lie on a 20 mesh sieve. The finer the material the greater resistance it offered to the passage of the electric current.



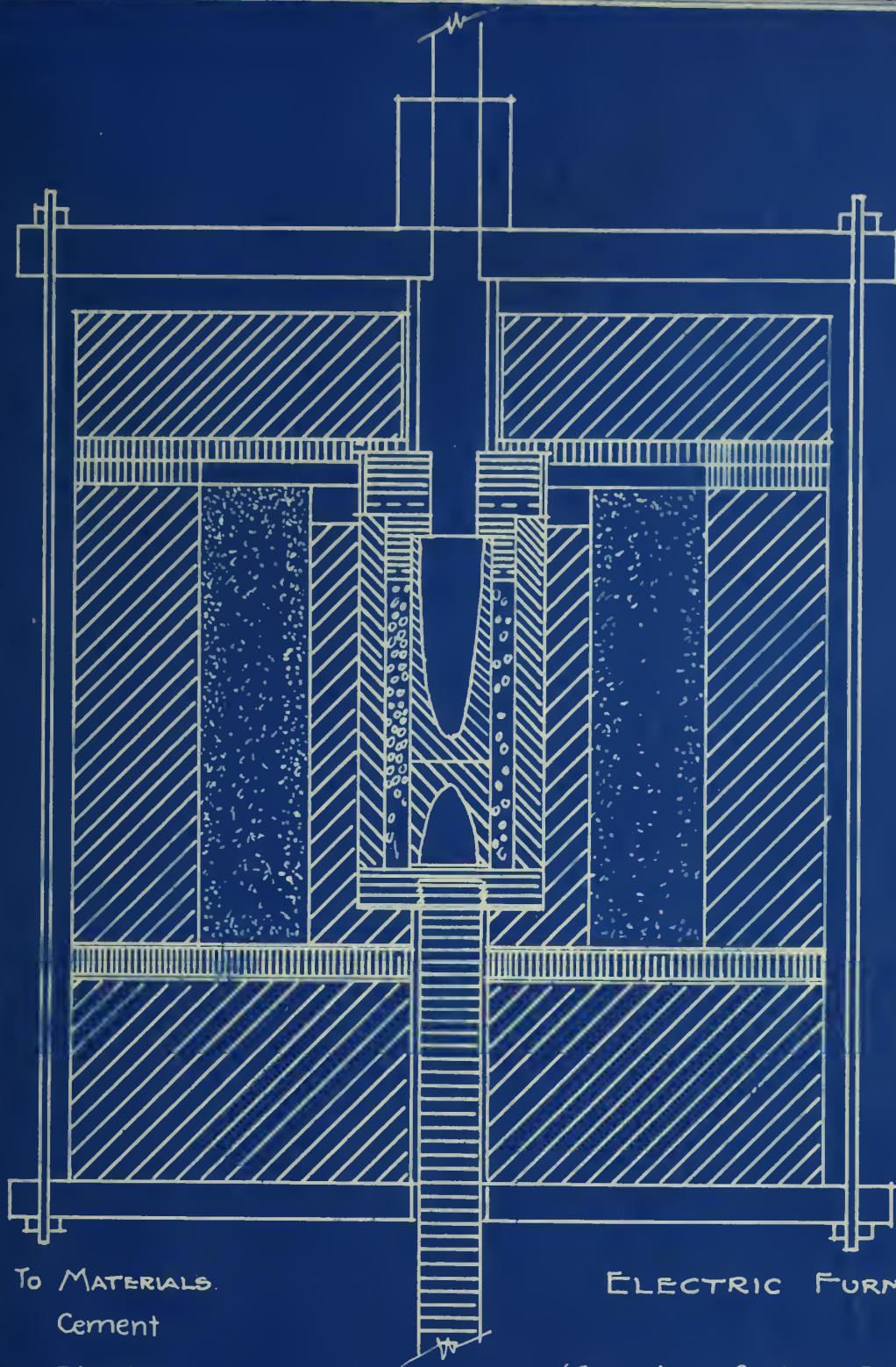


As finally constructed the total cross section of the resistor varied from 2 to 2.25 sq.in. Coke had such a high resistance that it was impossible to get sufficiently large currents through the furnace, especially when heating up from room temperature. With compressed carbon, which was obtained by grinding electric lantern electrodes, it was possible to get currents of about 10 amperes for heating up the furnace, increasing as the temperature increased. The initial current depends, in part, on whether or not the resistor has been packed and on the amount of pressure on the upper electrode, which is movable. With graphite the resistance is less and it is possible to get as much as 15 to 20 amperes in a short time. Graphite has the disadvantage that when a temperature of 1000 to 1200 degrees C is reached it becomes too good a conductor and that effect with the additional conductance due to the magnesia crucible and cylinder, which conduct appreciably above temperatures of about 1300 degrees, permits the passage of more than 30 amperes and it is necessary to use some external resistance. As a result a mixture of graphite and compressed carbon has been used. It seems most satisfactory to have the resistor so arranged that the furnace will start heating with a current of about 10 amperes without any external resistance. Then as the temperature of the furnace goes up the current increases until it reaches 25 to 30 amperes and it may be necessary to put in some external resistance in order to keep the current below 30 amperes. Slow heating, - heating to 1000 degrees in 15 to 20 minutes - seems to involve less danger of cracking the cylinders.

4. Adjustment of the Resistance. Beside the variation of the resistance by changing the composition of the resistor an



12A



KEY TO MATERIALS.

-  Cement
-  Fireclay
-  Magnesite
-  Asbestos
-  Granular Carbon
-  Graphite

ELECTRIC FURNACE

(Granular Carbon Resistance)

VERTICAL SECTION - B.

Scale  $\frac{3}{8}$ " = One Inch.

FIGURE 4B.

FIGURE

O.E. Harder.



LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS

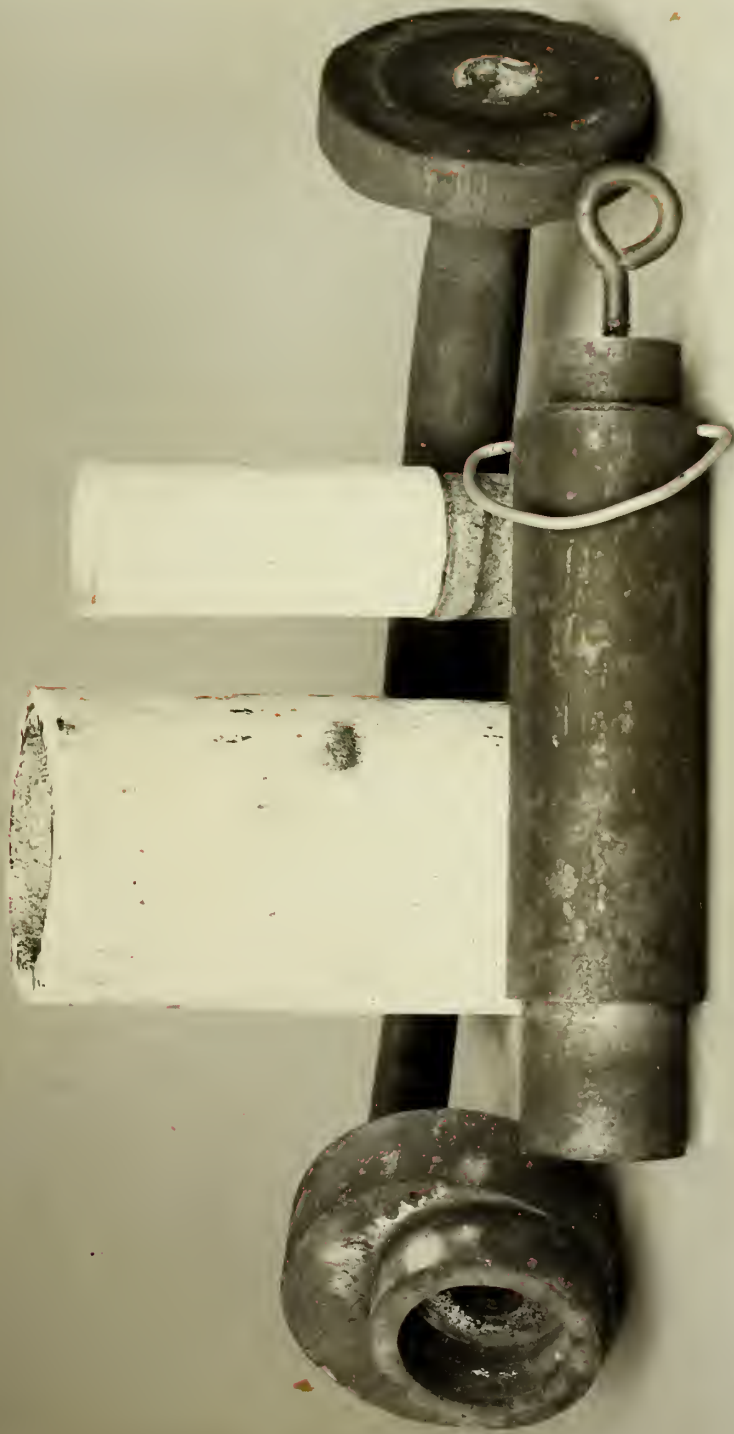
arrangement has been provided to change the pressure on the upper electrode by loosening or tightening the nuts on the cross piece shown in Figs. 4B and 6. This device gives considerable variation in the resistance and in some cases it has been found sufficient for all of the necessary control of the current, so that no external resistance was required.

5. Temperatures Obtainable. The highest temperature which has been measured has been  $1750^{\circ}\text{C}$ . as measured by a Wanner pyrometer. Chromium has been melted on several occasions. Temperatures of  $1400$  to  $1500^{\circ}\text{C}$ . have been obtained in 15 to 20 minutes but it is better to so operate the furnace that it will heat to  $1500^{\circ}\text{C}$ . in about 30 minutes and at that time will have a current of about 25 amperes with no external resistance.

6. Atmosphere in Furnace. The metal in the crucible is not in contact with carbon but it is exposed to oxidation. At higher temperatures there is generated in the furnace a sufficient amount of carbon monoxide so that it may be lighted above the openings in the furnace. That, to some extent, protects the charge from oxidation but it is not sufficient. A further protection has been secured by covering the charge with cryolite, which not only tends to prevent oxidation but fluxes most of the oxides which may have been formed.

7. Conclusions. While this furnace does not meet all of the desired requirements, it has some advantages. It is cheap and the parts can easily be replaced. It will produce temperatures as high as  $1750^{\circ}\text{C}$ . and will operate on a 110 volt circuit without a transformer. The crucible is large enough to hold a charge of 100 grams which is sufficient for cooling-curve determinations. By





Upper Electrode.    Magnesia Cylinder.    Crucible & Support.    Lower Electrode.  
Crucible Mould.

Fig.5





using a resistor of proper composition and adjusting the pressure on the electrode it is possible to make a considerable variation in the resistance and thus control the rate of heating, in most cases, without the use of external resistance.

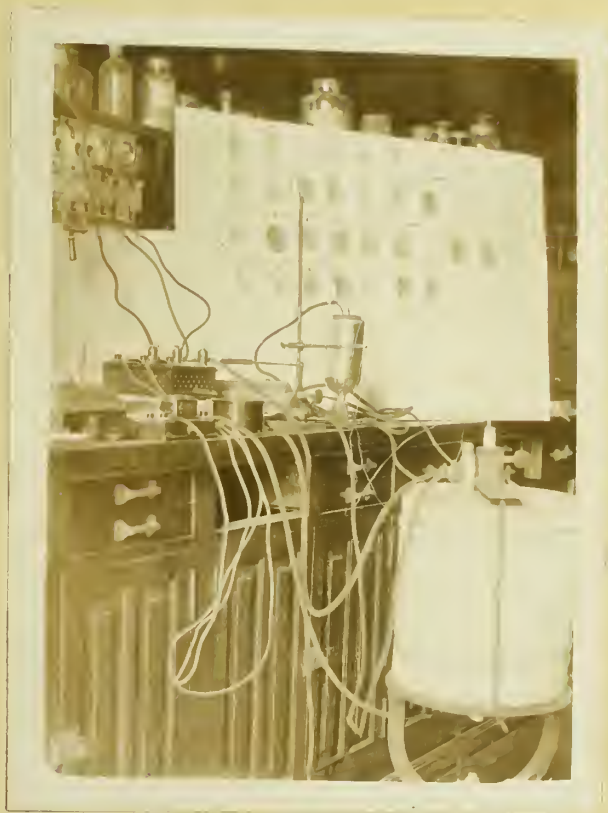


Fig.6 General View of Electric Furnace.



### III. PREPARATION OF THE ALLOYS.

1. Materials. The materials used in the preparation of the different alloys were all of good quality. The chromium was secured from the Goldschmidt Thermit Company and was labeled 98.99% chromium. An analysis of one sample showed 98.2 per cent chromium with the remainder consisting largely of silica, slag, etc. The nickel was C.A.F.Kahlbaum's "Nickel in Würfeln" and an analysis showed that it contained 99.6 per cent of nickel, a small amount of iron and only a trace of cobalt. Two different supplies of copper were used. Both were electrolytic copper; one purchased from the J.T.Baker Chemical Company and the other from C.A.F.Kahlbaum.

2. Melting the Metals. The samples, with the exception of Nos. 1 to 6 inclusive, were melted in a Hoskins electric furnace, of the carbon plate resistor type, in Crescent Safety crucibles bought from E.H.Sargent & Company of Chicago. They were sand crucibles covered with graphite. They stood temperatures as high as  $1600^{\circ}\text{C}$ . and in only one or two cases did they seem to be softened by the heat. It was not possible to use a crucible for more than one melt, principally because of the corrosion of the sand lining. Samples Nos. 1 to 6 inclusive were melted in a gas fired furnace in fire clay crucibles. The metals were protected in all cases by a cover of cryolite ( $\text{NaAlF}_4$ ) which was by far the most satisfactory cover found. It was necessary to have the metals covered to prevent oxidation, if possible, and at the same time it was desirable to have the cover of such a material that it would take up any oxides that were formed. The cover must also stand a





temperature of about  $1600^{\circ}\text{C}$ . without being lost by volatilization. Sodium and potassium carbonates, salt, borax, a mixture of these with silica, and magnesia were tried but they were all less satisfactory, due, in most cases, to volatilization. However, the mixture was a good flux for chromium oxide. Chromium does not seem to oxidize very rapidly below the melting point of copper and at that temperature the cryolite is quite liquid and covers the chromium. The charges were of uniform size, 300 grams, in all cases. The furnace used from 25 to 30 K. W. per hour and the time required for a melt varied from 2 to 3 hours.

3. Casting the Samples. The molten metals were poured into asbestos lined iron moulds  $3/4$  inches in diameter and about 8 inches in length, which had been heated to a bright red temperature and packed in amorphous silica. Some care was required in heating the moulds for if they were heated to too high a temperature the asbestos was broken up, and if not heated enough the moisture was not completely removed and caused trouble in pouring the metal. A method of pouring into moulds coated with lime was used for a while but that was found unsatisfactory and was abandoned. The lime was hard to dehydrate completely and then it scaled off and let the metal come in contact with the iron mould. By taking a reasonable amount of care it was possible to line the moulds with asbestos paper both on the sides and bottom, so that the metal did not come in contact with the iron and the casting could be removed with little difficulty when it was cold. If the bottom of the mould was not carefully closed with asbestos there was a decided tendency for the molten metal to flow up between the asbestos and the iron and that gave trouble in removing the casting.





The silica being a good nonconductor for heat insured slow cooling.

4. Composition of Alloys. The intended composition of the different alloys is given in Table No.1. The percentages are expressed in both atomic and weight per cents. The weight per cents were calculated from the atomic per cents by means of the following formula in which A, B, and C represent respectively the three metals chromium, copper and nickel.

Weight per cent A equals

$$\frac{\text{At. \% A} \times \text{at. wt. A} \times 100}{\text{At. \% A} \times \text{at. wt. A} + \text{at. \% B} \times \text{at. wt. B} + \text{at. \% C} \times \text{at. wt. C.}}$$

In these calculations the values Cr = 52.00; Cu = 63.57 and Ni = 58.68 were used as the atomic weights. Table No.1 also shows the weight per cent composition of the castings as found by analysis.

5. Analysis. Three methods of sampling were used. For some of the softer alloys the sample was obtained by making drillings. For the specimens which were turned to test pieces the turnings were used for analysis. In all other cases a piece was sawed off of one end of the specimen. The copper and nickel were determined electrolytically. The chromium was determined by precipitating it as the hydroxide, igniting and weighing as the oxide. Duplicate analyses were not made and some of the results show that the analyses are not highly accurate, but it is considered that all of the results are sufficiently accurate for the work in hand. In a few cases one of the constituents was determined by difference and that has been indicated in Table No.1.

6. Changes in Composition. A comparison of the composition of the charge with the composition of the casting, as found by





analysis, shows that there was a very remarkable loss in chromium content in the chromium-copper alloys. The highest chromium content found was in No.22 which showed 13.15 per cent, whereas, it should have had about 17 per cent. In No.31, the chromium should have been about 26 per cent but analysis showed only 9.89 per cent. Other attempts to prepare alloys of chromium and copper containing higher percentages of chromium failed. Even in the case of alloy No.12, which was slowly cooled and which contained only 6.08 per cent of chromium, there is a separation of pure chromium or of a chromium-rich constituent. See microphotograph No.12, Plate No.4. It has been stated by Hindrichs that, at higher temperatures, chromium and copper form an emulsion in which the chromium may be in a finely divided condition and that on slow cooling the chromium collects in larger particles. It seems more probable that chromium is much more soluble in copper at higher temperatures than at the melting point of copper. In either case rapid cooling may be expected to tend to prevent such a separation and to produce a more homogeneous structure. Evidence to this effect is shown by the fact that the alloy containing 10 per cent of chromium and 90 per cent of copper which is offered for sale by the Goldschmidt Thermit Company is almost homogeneous. That alloy is said to be made by an aluminothermic method. The aluminothermic reaction would produce a very high temperature; then if, as appears to be the case, the alloy is cooled suddenly there would not be sufficient time for the separation of the chromium or chromium-rich constituent.

In the case of the other alloys there were losses of different constituents depending upon a number of conditions. For the ternary alloys rich in copper there was generally a loss in chromium,



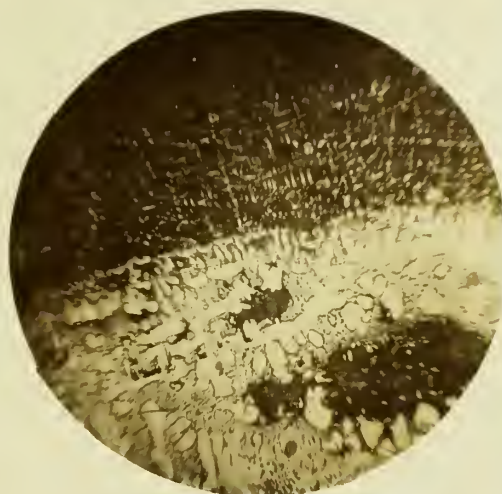
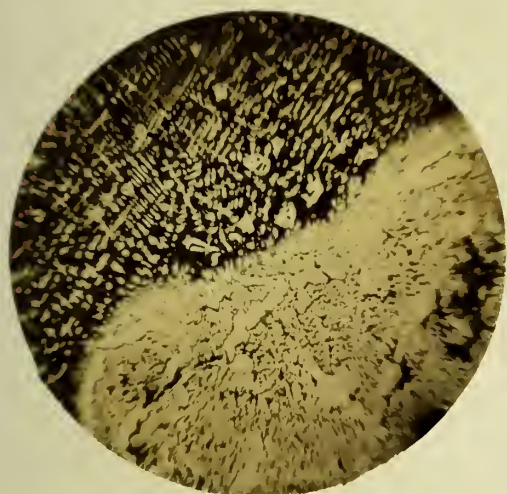
probably due to a lack of solubility of the chromium in the other metals present. For the ternary alloys rich in nickel and for the binary alloys of chromium and nickel there was generally a loss in nickel, but that may be accounted for by the fact that in making up the charges precaution was taken to protect the chromium by putting it in the bottom of the crucible and that left the nickel more exposed to oxidation. The changes in composition may be studied in Table No.1. It is certain that in making a series of alloys by such a method as has been outlined above it is not safe to assume that the composition of the alloy obtained will be the same as that of the charge melted.

7. Alloy of 50% Cr and 50% Cu. In order to determine whether or not an alloy containing equal parts of chromium and copper could be prepared the following experiments were conducted. A charge of 30 grams of chromium and 30 grams of copper was heated in the furnace which has been described in Chapter II. A little copper was put in the bottom of the crucible, next the chromium was added and then the remainder of the copper. The charge was covered with cryolite. It was heated well above the melting point of chromium and kept at that temperature for at least 15 minutes. The current was then shut off and the furnace allowed to cool slowly. An examination showed that the chromium had been melted. The copper had been put on top of the charge but it was found at the bottom of the melt. A fairly well defined line of separation between the copper-rich and the chromium-rich parts of the melt could be seen. See microphotographs below. The above experiment was later repeated with similar results. By this method it has been possible to get a division of the melt into two fairly well





defined layers. From a microscopic examination it was evident that the lower layer contained some chromium and it appeared that the upper layer contained some copper. Hindrichs stated that he was not able to get the two metals to separate into two sharply defined layers.



Microphotographs showing the separation of the chromium-rich and the copper-rich constituents of a melt containing 50% Cr and 50% Cu. Etched in 1%  $\text{FeCl}_3$  in 1:1 HCl and then stained in I in alcohol. The dark portion is the copper-rich constituent. Magnified 44 diameters.

LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS

Table No.1

22.

No.	Atomic per cent composition			Weight per cent composition			Weight per cent comp. by analysis		
	<u>Cu</u>	<u>Cr</u>	<u>Ni</u>	<u>Cu</u>	<u>Cr</u>	<u>Ni</u>	<u>Cu</u>	<u>Cr</u>	<u>Ni</u>
1.	100.			100.					
2.	90.		10.	90.71		9.29	90.84		9.06
3.	80.		20.	81.27		18.73	81.07		18.76
4.	70.		30.	71.65		28.35	71.16		28.46
5.	60.		40.	61.90		38.10	61.63		38.25
6.	50.	(1)	50.	52.00		48.00	48.96		49.90
7.	40.		60.	41.94		58.06	69.13		30.59
8.	30.		70.	31.70		68.30	41.14		58.27
9.	20.		80.	21.31		78.69	20.65		79.35*
10.	10.		90.	10.74		89.26	10.57		88.90
11.			100.			100.	00.00		99.66
12.	90.	10.		91.68	9.32		94.20	6.08	00.00
13.	80.	10.	10.	82.12	8.40	9.48	84.36	7.79	9.28
14.	70.	10.	20.	72.43	8.45	19.12	74.63	8.25	16.05
15.	60.	10.	30.	62.58	8.53	28.89	66.32	10.63	22.94
16.	50.	10..	40.	52.57	8.60	38.83	54.71	15.94	29.35
17.	40.	10.	50.	42.40	8.67	48.93	42.56	10.13	48.00
18.	30.	10.	60.	32.05	8.75	59.20	32.69	13.97	54.16
19.	20.	10.	70.	21.55	8.81	69.64	20.85	11.80	66.25
20.	10.	10.	80.	10.87	8.89	80.24	11.83	11.90	76.27*
21.		10.	90.		8.96	91.04	00.00	19.37	78.99
22.	80.	20.		83.02	16.98		87.93	13.15	00.00

(1) No.6 was made up to be 50% copper and 50% nickel by weight.

\* Determined by difference.





Table No.1 continued

23.

No.	Atomic per cent composition			Weight per cent composition			Weight per cent comp. by analysis		
	<u>Cu</u>	<u>Cr</u>	<u>Ni</u>	<u>Cu</u>	<u>Cr</u>	<u>Ni</u>	<u>Cu</u>	<u>Cr</u>	<u>Ni</u>
23.	70.	20.	10.	73.22	17.12	9.66	80.58	10.56	9.38
24.	60.	20.	20.	63.28	17.25	19.47	56.30	14.56	29.24
25.	50.	20.	30.	53.16	17.40	29.44	66.92	13.62	19.20
26.	40.	20.	40.	42.88	17.54	39.58	44.08	19.30	36.34
27.	30.	20.	50.	32.41	17.69	49.90	36.70	15.99	47.31*
28.	20.	20.	60.	21.80	17.83	60.37	22.20	19.86	57.36
29.	10.	20.	70.	10.99	17.98	71.03	10.88	19.64	68.62
30.		20.	80.		18.14	81.86	00.00	21.52	76.95
31.	70.	30.		74.05	25.95		89.82	9.89	00.00
32.	60.	30.	10.	63.99	26.17	9.84	73.63	17.66	8.55
33.	50.	30.	20.	53.77	26.38	19.85	59.62	22.00	19.48
34.	40.	30.	30.	43.37	26.61	30.02	45.70	25.10	29.52
35.	30.	30.	40.	32.79	26.84	40.37	33.76	29.46	36.78*
36.	20.	30.	50.	22.05	27.06	50.89	22.58	28.10	48.42
37.	10.	30.	60.	11.12	27.29	61.59	10.90	29.70	58.12
38.		30.	70.		27.52	72.48	00.00	28.44	71.56*
39.	60.	40.		64.71	35.29		Not prepared.		
40.	50.	40.	10.	54.38	35.58	10.04	70.57	19.93	8.99
41.	40.	40.	20.	43.86	35.89	20.25	54.16	31.63*	14.21
42.	30.	40.	30.	33.17	36.20	30.63	33.60	38.16	26.78
43.	20.	40.	40.	22.31	36.50	41.19	22.68	41.32	34.60
44.	10.	40.	50.	11.25	36.82	51.93	11.02	43.30	46.46
45.		40.	60.		37.14	62.86	00.00	44.93	56.55
46.	50.	50.		55.20	44.80		Not prepared.		
47.	40.	50.	10.	44.38	45.37	10.25	Not prepared.		

\* Determined by difference.



Table No.1 continued

24.

No.	Atomic per cent composition			Weight per cent composition			Weight per cent comp. by analysis		
	<u>Cu</u>	<u>Cr</u>	<u>Ni</u>	<u>Cu</u>	<u>Cr</u>	<u>Ni</u>	<u>Cu</u>	<u>Cr</u>	<u>Ni</u>
48.	30.	50.	20.	33.57	45.76	20.67	28.42	54.92	17.12
49.	20.	50.	30.	22.58	46.16	31.26	24.12	47.54	26.28
50.	10.	50.	40.	11.39	46.56	42.05	Not analyzed.		
51.		50.	50.		46.96	53.04	00.00	57.40	41.66
52.	40.	60.		44.89	55.11				
53.	30.	60.	10.	33.96	55.59	10.45			
54.	20.	60.	20.	22.85	56.06	21.09			
55.	10.	60.	30.	11.53	56.56	31.91	Not analyzed.		
56.		60.	40.		57.07	42.93	Not analyzed.		
57.	30.	70.		34.37	65.63				
58.	20.	70.	10.	23.13	66.21	11.56			
59.	10.	70.	20.	11.66	66.80	21.54			
60.		70.	30.		67.40	32.60	Not analyzed.		
61.	20.	80.		23.41	76.59				
62.	10.	80.	10.	11.81	77.29	10.90			
63.		80.	20.		78.00	22.00	Not analyzed.		
64.	10.	90.		11.96	88.04				
65.		90.	10.		88.86	11.14	Not analyzed.		
66.		100.			100.			98.21	





#### IV. THERMAL ANALYSES AND HEAT-TREATMENTS.

1. Difficulties of Thermal Analysis. The principal reason for constructing the electric furnace, described in Chapter II., was to secure a suitable furnace for making thermal analyses of the alloys. Although the furnace seemed to promise well, other difficulties were met. It was necessary to have an insulating tube for the thermocouple. Quartz tubes are good for lower temperatures but they cannot be used at the melting point of chromium. Porcelain tubes, such as were used by Hindrichs, stand slightly higher temperatures than quartz without softening but they break badly and are attacked by chromium. An attempt was made to use an alundum tube but it broke in the first melt. Since it was known that the magnesia crucibles were little attacked by the chromium, it was thought that an insulating tube of the same material might be satisfactory. Some tubes were moulded, dried and heated to about  $1500^{\circ}\text{C}$ . They became hard and dense, but bent during the heating. It appears that in heating the magnesia to  $1500^{\circ}\text{C}$ ., it passes through a semi-fused state at which time sintering takes place, but at that same time the tubes bent so badly that they could not be used. Some magnesia tubes were moulded in which a solution of magnesium chloride was used as the binding material. These tubes after drying at  $105^{\circ}\text{C}$ . were hard and looked promising, but when they were heated they became brittle and crumbled to pieces at 800 to  $900^{\circ}\text{C}$ . So far all attempts to prepare satisfactory magnesia insulating tubes have failed. Because of so many difficulties and a limited amount of time it was thought best to omit this part of the investigation for the time being.



2. Heat-Treatments. As was explained in the Introduction, it has not been considered advisable to do much in the way of heat-treatment until the equilibrium diagrams have been established.

Annealing Tests:- Small pieces of alloys, Nos. 22 to 38 inclusive, were packed in amorphous silica in an iron pipe, 1-3/4 by 5 inches in dimensions and closed at both ends by caps. The pipe and contents were placed in an electric furnace and heated at a temperature of approximately 900°C. for at least 24 hours. The specimens were repolished and examined microscopically. From a brief examination it seems that there had not been any very noticeable change in the structure.





## V. PHYSICAL AND MECHANICAL PROPERTIES.

1. Color and Appearance. The color of the different alloys depends upon the amount of copper as compared with the sum of the amounts of chromium and nickel present. The chromium and nickel colors are more persistent than the copper color and an alloy containing 50 per cent of copper and 50 per cent of nickel, or of chromium and nickel, will have the color of nickel and will not show any color of copper. The alloys near the pure copper corner of the diagram (See Fig.7) show the greatest tendency to tarnish when exposed to the air in the laboratory. On the other hand, the alloys near the nickel corner of the diagram are more porous and more likely to have blow-holes. Perhaps the diagram used in Fig.7 requires a word of explanation. The three metals, chromium, copper and nickel, are represented by the corners of the equilateral triangle. The compositions of the different alloys, as found by analysis, have been represented by the centers of the circles so that they can be read off directly from the diagram. The number of the alloy has been placed inside of the circle. All of the binary alloys fall on the sides of the triangle and all of the ternary alloys fall within the triangle. One example will serve to show the method of reading the composition of the different alloys from their position on the diagram. No.28 is approximately on the line marked 20 per cent chromium which runs parallel to copper-nickel side of the triangle. It is between the lines marked 60 and 50 per cent of nickel which run parallel to the chromium-copper side of the triangle. From that it can be estimated that the alloy contains approximately 57 per cent of nickel.



Then there is left about 23 per cent for copper or it can be read off from the distance of the center of the circle from the line marked 20 per cent copper which runs parallel to the chromium-nickel side of the triangle. By this method it is possible to read off directly the composition of any alloy which has been plotted on the diagram. The alloys which show the copper color are Nos. 2, 3, 4, 5, 12, 13, 14, 22, 23, 31, 32, 40 and 48. Their compositions can be read off from Fig.7 or it can be found in Table No.1. Table No.2 shows in a brief way the kinds of castings which were obtained for the different alloys.

2. Specific Gravity. The specific gravities of the different alloys, as cast, are given in Table No.2 and the same results are shown in Fig.7. In the diagram the specific gravity of the alloy has been written above the circle representing the composition of the alloy. The specific gravities were determined by weighing in air and in distilled water at 25°C. and then calculating the specific gravity from the formula:

$$\text{Sp. gr.} = \frac{\text{Wt. in air at } t^{\circ}\text{C.} \times \text{sp. gr. H}_2\text{O at } t^{\circ}\text{C.}}{\text{Loss of wt. in H}_2\text{O at } t^{\circ}\text{C.}}$$

The maximum variation of the temperature from 25°C. was not more than plus or minus 0.5°C. and since that variation in the temperature changed the specific gravity of H<sub>2</sub>O only 0.001 all calculations were made using the specific gravity of H<sub>2</sub>O at 25°C. The specimens used in these determinations usually weighed about eight grams, they had been ground smooth on a No.100 alundum wheel and were carefully freed from grease etc. They were suspended by a fine silk thread when weighed in water. The thread had very little surface tension and the weights could be made accurate to



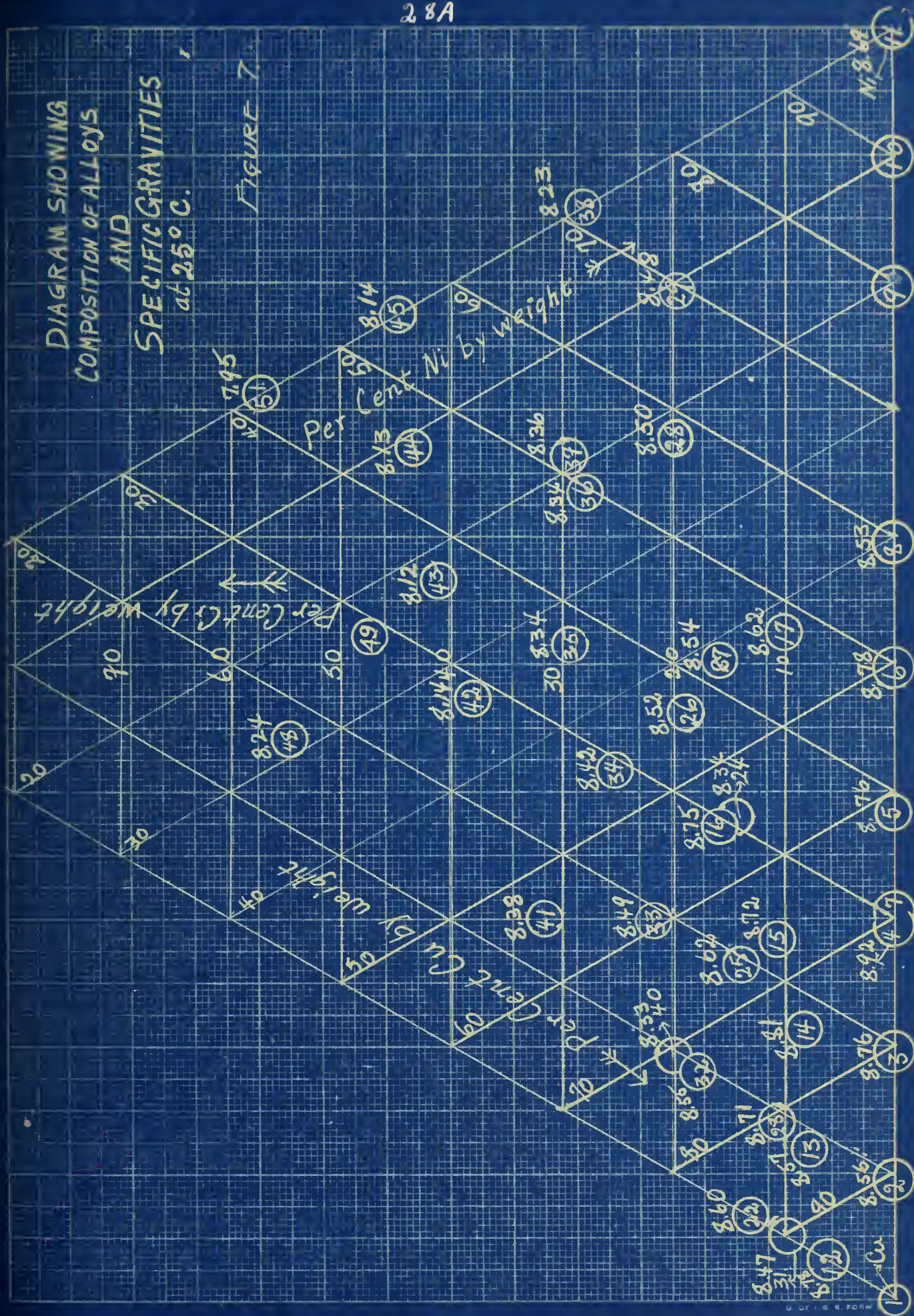




# DIAGRAM SHOWING COMPOSITION OF ALLOYS

## AND SPECIFIC GRAVITIES at 25°C.

FIGURE 7





LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS

## HARDNESS, SPECIFIC GRAVITY AND KIND OF CASTING.

No.	Diameter of Impression	Brinell Hardness Number	Specific Gravity at 25°C.	Kind of Casting.
1.				Good.
2.	Broke in test.		8.56	Good.
3.	Cracked in test.		8.76	Medium.
4.	Cracked in test.		8.92	Blow-holes in places.
5.	Specimen too small.		8.76	Blow-holes in places.
6.	Specimen too small.		8.78	Good.
7.	7.2	Below 68.	8.53	Good.
8.	-----	-----	-----	Casting had blow-holes.
9.	-----	-----	-----	Blow-holes all through.
10.	-----	-----	-----	Blow-holes in places.
11.	Broke in test. (5.4 mm. thick)		8.69	Large crystals and small blow-holes.
12.	7.2	Below 68.	8.78	Good.
13.	6.3	86.	8.57	Sound.
14.	5.8	103.	8.81	Sound.
15.	5.0	143.	8.72	Sound.
16.	4.73	161.	8.75	Small, but sound.
17.	4.7	163.	8.62	Fair.
18.	-----	-----	-----	Small blow-holes.
19.	-----	-----	-----	Fair, except for blow-holes.
20.	-----	-----	-----	Fair, except for blow-holes.
21.	-----	-----	-----	Large blow-holes.
22.	6.9	69.	8.60	Sound throughout.
23.	6.4	82.	8.71	Good.
24.	6.2	89.	8.34 (?)	Good.





No.	Diameter of Impression	Brinell Hardness Number	Specific Gravity at 25°C.	Kind of Casting.
25.	5.9	99.	8.62	Good.
26.	4.8	156.	8.52	Very good.
27.	4.53	175.	8.54	Sound.
28.	4.5	179.	8.50	Sound.
29.	5.3 (Specimen small)	126.	8.48	Sound.
30.	-----	-----	-----	Large blow-holes.
31.	7.3	68.	8.47	Medium.
32.	5.46	117.	8.55	Small, but sound.
33.	5.5	116.	8.49	Excellent. There was some segregation of Cr at top of casting.
34.	5.3	126.	8.42	Good.
35.	4.92	148.	8.34	Excellent.
36.	4.6	170.	8.34	Excellent.
37.	4.7	163.	8.36	Excellent.
38.	4.48	181.	8.23	Good.
39.	Not prepared.			
40.	5.4	121.	8.33	Small, but sound.
41.	5.5	116.	8.38	Good.
42.	5.2	131.	8.14	Excellent.
43.	4.8	156.	8.12	Excellent.
44.	4.7	163.	8.13	Excellent.
45.	4.93 (Cracked in test.)	147. (?)	8.14	Good.
46.	Not prepared.			
47.	Not prepared.			
48.	5.7	107.	8.24	Excellent.



Table No.2 continued.

No.	Diameter of Impression	Brinell Hardness Number	Specific Gravity at 25°C.	Kind of Casting.
49.	-----	-----	-----	Sound.
50.	4.25	202.	7.89	Good.
51.	4.5	179.	7.95	Good.
55.	4.0	228.	-----	Sound.
56.	4.5 (Specimen too small)	179. (?)		Sound.
60.	-----	-----	-----	Sound.
63.	-----	-----	-----	Sound.
65.	-----	-----	-----	Sound.



Date	Description	Amount	Balance
1890	Jan 1		100.00
	Feb 1	50.00	50.00
	Mar 1	25.00	25.00
	Apr 1	10.00	15.00
	May 1	75.00	40.00
	Jun 1	30.00	10.00
	Jul 1	15.00	5.00
	Aug 1	10.00	5.00
	Sep 1	5.00	5.00
	Oct 1	5.00	5.00
	Nov 1	5.00	5.00
	Dec 1	5.00	5.00
	Total	250.00	250.00

less than 1. milligram. The thread was attached to a piece of wire which was hung on the balance. The thread and wire were weighed frequently and corrections were made for their weight. The value obtained for No.24 was in error because it was afterwards found that the specimen contained a concealed blow-hole. If the alloys containing a constant amount of chromium with varying amounts of copper and nickel are considered, it will be seen that there is little variation in the specific gravity. On the other hand, if the alloys containing a constant amount of copper with varying amounts of chromium and nickel are considered, it will be seen that the specific gravity decreases as the per cent of chromium increases. Similar results may be obtained if the alloys containing constant amounts of nickel and varying amounts of chromium and copper are examined. If the specific gravities are plotted as ordinates and the per cents of chromium as abscissas, fairly regular curves will be obtained. If the exact composition of the alloy is known it is possible to get some idea of the relative porosity of the specimen by a study of the specific gravities.

3. Brinell Hardness Number. The hardness measurements were made in the Materials Testing Laboratory of the Department of Theoretical and Applied Mechanics of the University of Illinois with a Brinell instrument using a 3000 kilogram load and a ball of 10 mm. diameter and applying the pressure for 15 seconds. The diameters of the impressions were carefully measured and the hardness numbers corresponding to those diameters were found in a table supplied by the makers of the instrument. The pieces tested had been ground smooth, were from 4-8 mm. thick and about 20 mm. in diameter. Only one test was made on each piece and if it was noticed that the piece had bulged or cracked from the pressure



that fact was recorded or the results were rejected.

Specimen No.11 requires special mention. It was a sample of pure nickel which had been melted in a magnesia crucible and slowly cooled. It had very large crystals (See microphotograph No.11) and when a test piece 5.4 mm. thick and 22 mm. in diameter was tested it broke at a load of about 2000 kilograms.

Some of the specimens were especially hard as may be seen from a comparison with the values which are given in the following table. \*

\* Canada Department of Mines, Report No.309. Part II.  
By Kalmus and Harper. Page 9.

Material	Date	Load	Brinell Hardness
Copper, rolled sheet, unannealed,	Jan. 1913	1000 lbs.	65.6
" , " , "	" 1914	1000 "	67.4
" , " , "	" 1914	3500 "	75.0
" , " , "	" 1914	3500 "	81.9
Swedish iron	Jan. 1913	3500 "	90.7
" "	" 1914	1000 "	68.6
" "	" 1914	3500 "	75.2
Wrought iron	Jan. 1913	3500 "	92.0
" "	" 1914	1000 "	83.1
" "	" 1914	3500 "	100.2
Cast iron	Jan. 1913	3500 "	97.8
" "	" 1914	1000 "	84.4
" "	" 1914	3500 "	104.5
Mild steel	Jan. 1913	3500 "	109.9
" " , cold rolled shafting	" 1914	3500 "	126.2





Material	Date	Load	Brinell Hardness
Tool steel	Jan. 1913	3500 lbs.	153.8
" " "Crescent"	" 1914	3500 "	130.2
Spring steel	Jan. 1913	3500 "	160.3
" "	" 1914	3500 "	178.0
Tool steel, self-hardening	Jan. 1913	3500 "	180.0
" " " " "Rex" (before hardening)	" 1914	3500 "	162.1
Tool steel, self-hardening "Rex" (after hardening)	" 1914	3500 "	240.0
Tool steel, self-hardening, from work shop (School of Mines)	Jan. 1914	3500 "	259.0
Cobalt		3500 "	124.

It is evident that these alloys are as hard as tool steel and sample No.55 approaches that of self-hardening tool steel after hardening. It is likely that some of the alloys in this series have still greater hardness than the one referred to above since some of the others contain more chromium.

The hardness of these specimens has made them extremely difficult to work. A saw blade has been ruined on some of the specimens without cutting more than 1 mm. deep. It has been found that by keeping the saw blades moist with terpentine they will last somewhat longer.

The results obtained by the hardness tests are shown in Table No.2.

#### 4. Tensile Strength and Stress-Deformation Tests.

Eighteen specimens of the alloys of various compositions were turned down to test pieces and their ultimate tensile strengths



determined and in all except two cases their elongations under stresses were measured.

Test Pieces:- The test pieces were from 3 to 4 inches in total length and were turned to a diameter of approximately 0.300 inches for a length of 2.0 inches and were threaded at the ends so that they could be screwed into half inch grips. It was necessary to make the measurements on these short test pieces instead of the usual eight inch specimens because the original castings were only 4 to 5 inches long and pieces had been cut off for microscopic examination, for corrosion tests, etc. It is likely that some of the irregularities observed in the values obtained for the modulus of elasticity and for the ultimate tensile strength should be attributed to the use of the short test pieces.

Testing Machine and Method of Loading:- The testing machine on which the tests were made was an Olsen, Universal, Screw-Power Testing Machine of 10,000 pounds capacity. The loading was by hand and quite slow except <sup>that</sup> in the case of specimens No.17 and No. 28 the loading was done with the motor and was more rapid. The loading was continuous and not repeated.

Extensometer:- A Ewing extensometer having a gage of 1.25 inches was used in measuring the elongations. The instrument was quite sensitive and the elongations could be read accurately to 0.00008 inches and estimated to 0.000008 inches. The initial or zero extensometer reading was taken with a small load on the machine. After a satisfactory number of readings had been made the extensometer was removed and load increased until the specimen broke.





Calculation of Modulus of Elasticity:- Curves were plotted with stresses as ordinates and elongations as abscissas. Then tangents to the curves were drawn and extended to a point which corresponded to an elongation of 0.001 inch on a length of 1.0 inch and the stress corresponding to that elongation was read from the cross-ruled paper. That stress minus the initial stress for zero elongation gave the modulus of elasticity. The values are given in round numbers.

The results are shown in the following table:

Table No.3

No.	Composition of the alloy as found by analysis			Modulus of Elasticity in lb. per sq.in.	Ultimate Tensile Strength in lb. per sq. in.	
	Cr	Cu	Ni			
14.	8.25	74.63	16.05	18,000,000	19,978	
17.	10.13	42.56	48.00	-----	23,833	
25.	13.62	66.92	19.20	7,000,000	14,880	(1)
24.	14.56	56.30	29.24	20,000,000	17,521	
26.	19.30	44.08	36.34	12,000,000	14,802	
28.	19.64	22.20	57.36	-----	56,255	
29.	19.64	10.88	68.62	7,000,000	19,846	(2)
33.	22.00	59.26	19.48	17,600,000	22,650	
34.	25.10	45.70	29.52	20,000,000	25,768	
36.	28.10	22.58	48.42	23,700,000	32,654 plus	
38.	28.44	-----	71.56	15,800,000	36,958	
35.	29.46	33.76	36.78	16,300,000	38,734	
37.	29.70	10.90	58.12	22,000,000	29,630	
42.	38.16	33.60	26.78	26,400,000	7,449	
44.	43.30	11.02	46.46	16,300,000	29,587	
49.	47.54	24.12	26.28	43,200,000	22,336 plus	



Table No.3 continued

No.	Composition of the alloy as found by analysis			Modulus of Elasticity in lb. per sq.in.	Ultimate Tensile Strength in lb. per sq. in.
	Cr	Cu	Ni		
48.	54.92	28.42	17.12	57,000,000	33,842 (2)
51.	57.40	-----	41.66	48,000,000	37,200

(1) Showed a flaw at the fracture.

(2) The threads were not straight and these values are considered less reliable than the others.

The above specimens have been tabulated so that the per cent of chromium increases from the top to the bottom.

The following is given as typical set of data and the complete data for each specimen will not be included:

Alloy No.35.

Diameter 0.305 in.

Cross-section, 0.07306 sq. in.

Extensometer Readings.	Elongation in .0008 in.	Load in Pounds	Unit Load	Remarks
3.00	0.0000	150.	2,053	
3.30	0.30	380.	5,201	
3.63	0.63	625.	8,554.	
3.93	0.93	894.	12,236	
4.23	1.23	1140.	15,603	
4.55	1.55	1385.	18,956	
4.83	1.83	1625.	22,241	
5.18	2.18	1790.	24,500	
5.60	2.60	2000.	27,374	
Ultimate		2830.	38,734	

Reduction and Elongation:- The per cent of reduction of area was quite small in all cases, in fact, it was so slight that





measurements with a micrometer would not give appreciable decreases in diameters. The curves in Figs. 8 to 12 will show that the elongations were small. These alloys do not show well defined yield points or elastic limits but show a gradual flattening of the stress deformation curves until the ultimate is reached. The curves are similar to those for cast iron.

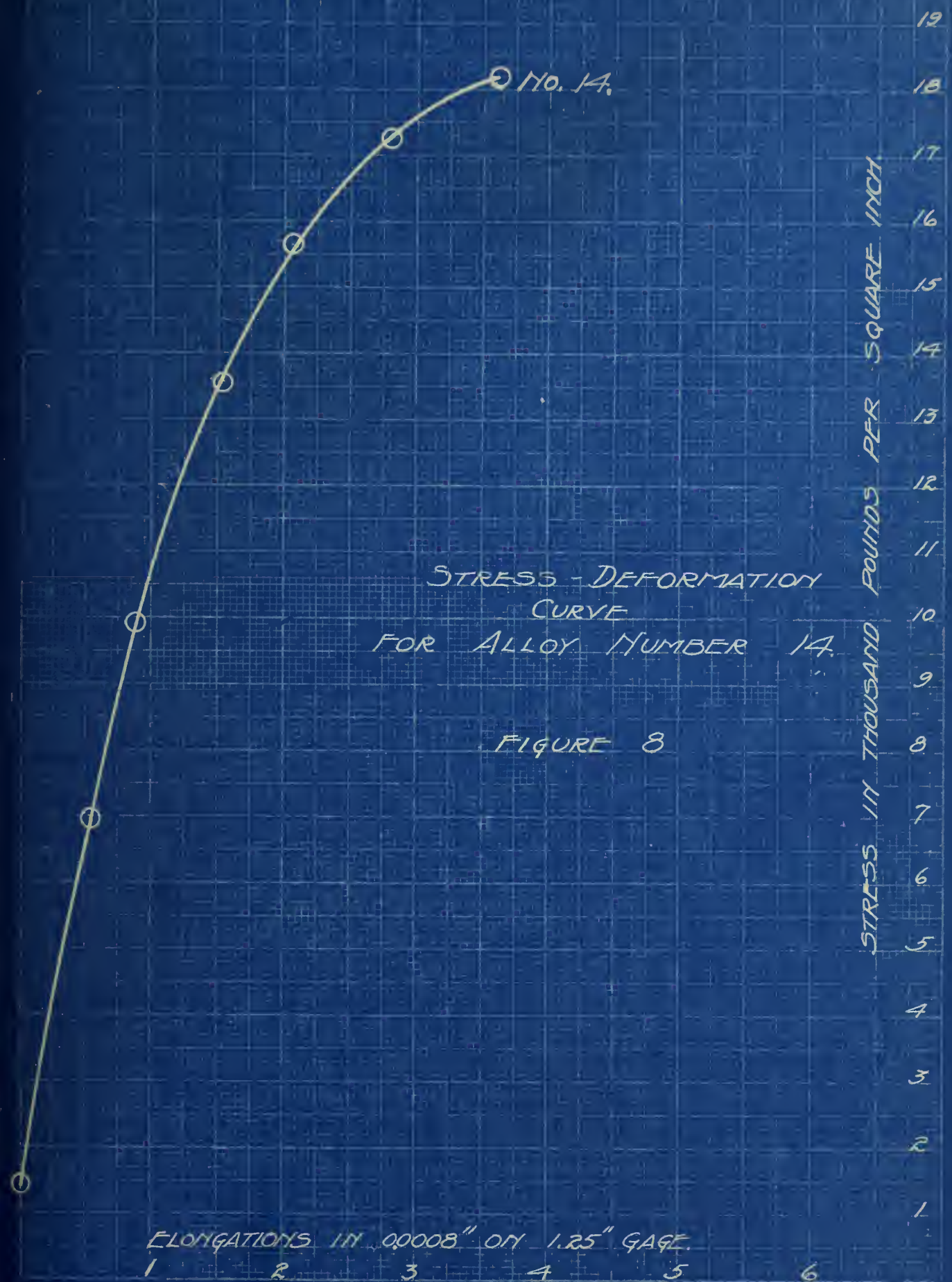
Ultimate Strength:- The ultimate tensile strength varied from 7,449 to 56,255 pounds per square inch cross-section. It seems that the binary alloy of chromium and nickel has more ultimate tensile strength than the ternary alloy in which 10 per cent of the nickel has been replaced by copper. See Nos. 38 and 37. However, it does not seem possible to draw any very general conclusions from these results as to what composition will have the greatest tensile strength. It is felt that the remarkably low ultimate strength for No.42 is due to the fact that it contains a large amount of chromium (38.16 per cent) and at the same time a large amount of copper (33.60 per cent) which would seem to produce an unstable condition because it has not been possible to prepare alloys of copper and chromium containing more than about 13 per cent of chromium.

Modulus of Elasticity:- While there are some irregularities in the values obtained, it seems that the modulus of elasticity increases with increase in chromium content. The values obtained may be said to vary from 15,000,000 to more than 40,000,000, or by way of comparison, they vary from one half to one and one half the value for iron and steel.

A general idea of the properties of these alloys may be gotten from the stress-deformation curves which are given in Figs.8 to 12.









LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS

STRESS IN THOUSAND POUNDS PER SQUARE INCH.

STRESS-DEFORMATION CURVES  
FOR ALLOYS 24-25-26 AND 29.

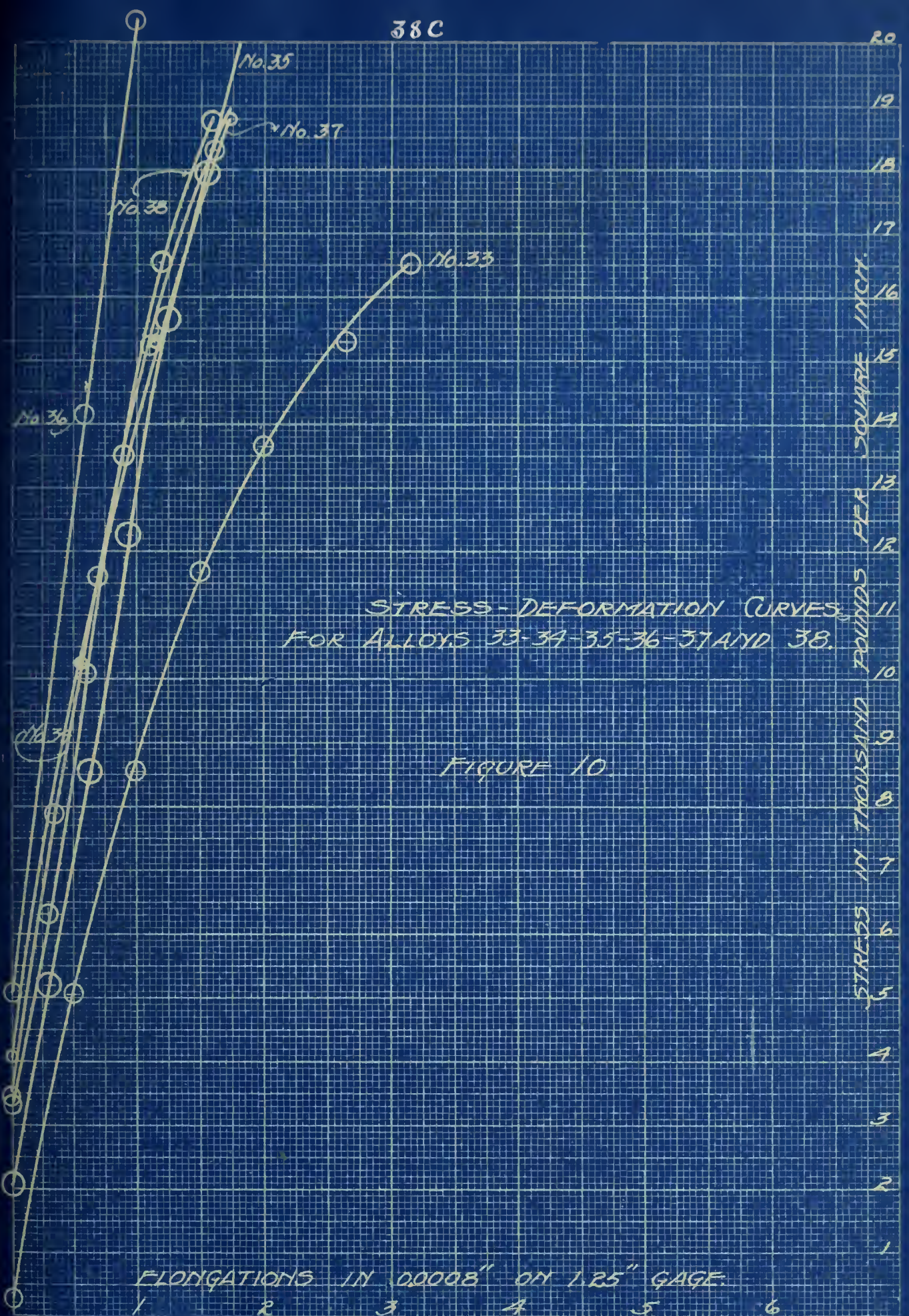
FIGURE 9.

ELONGATIONS IN 00008" ON 1.25" GAGE

1 2 3 4 5 6

LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS





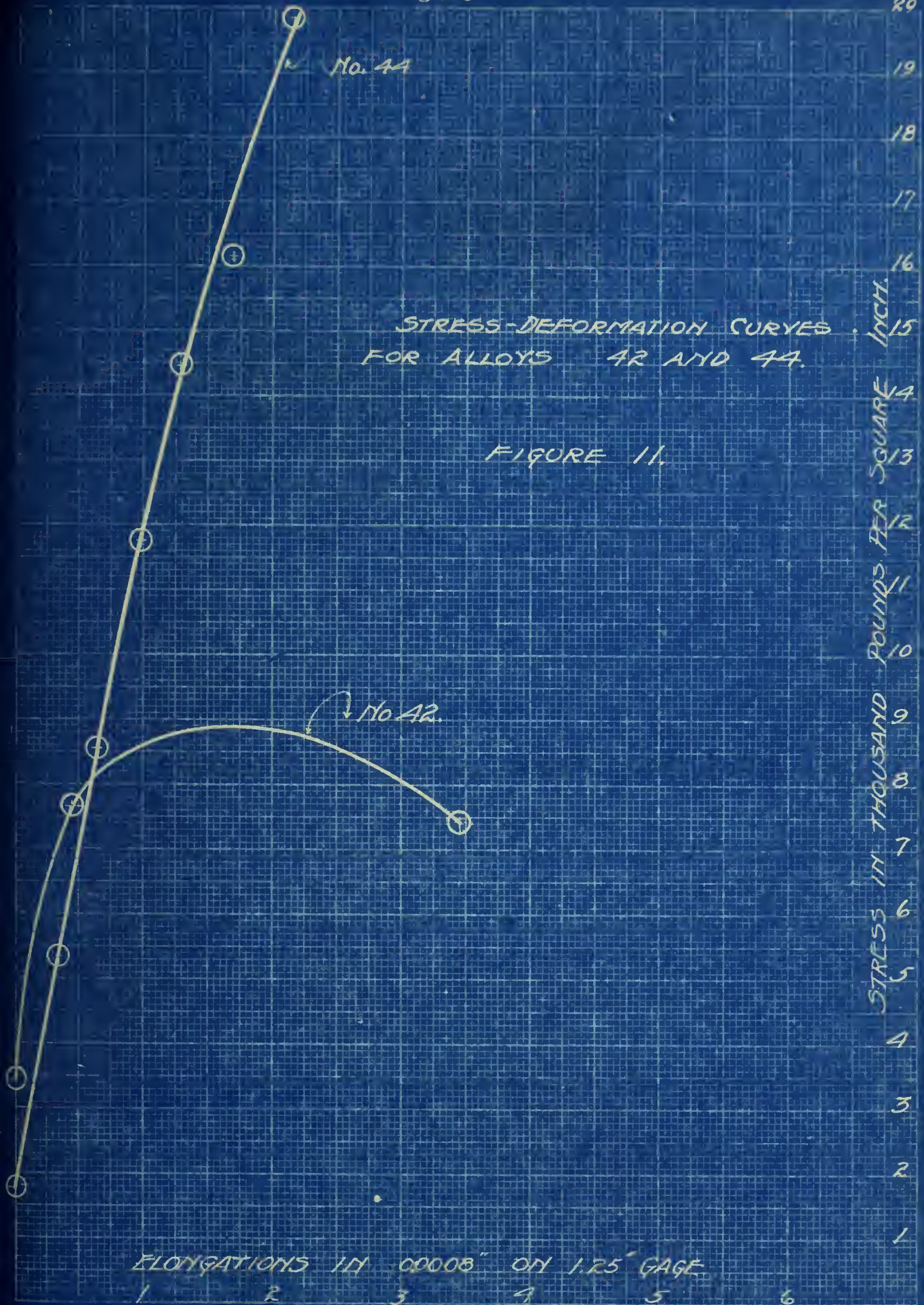


LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS

No. 44

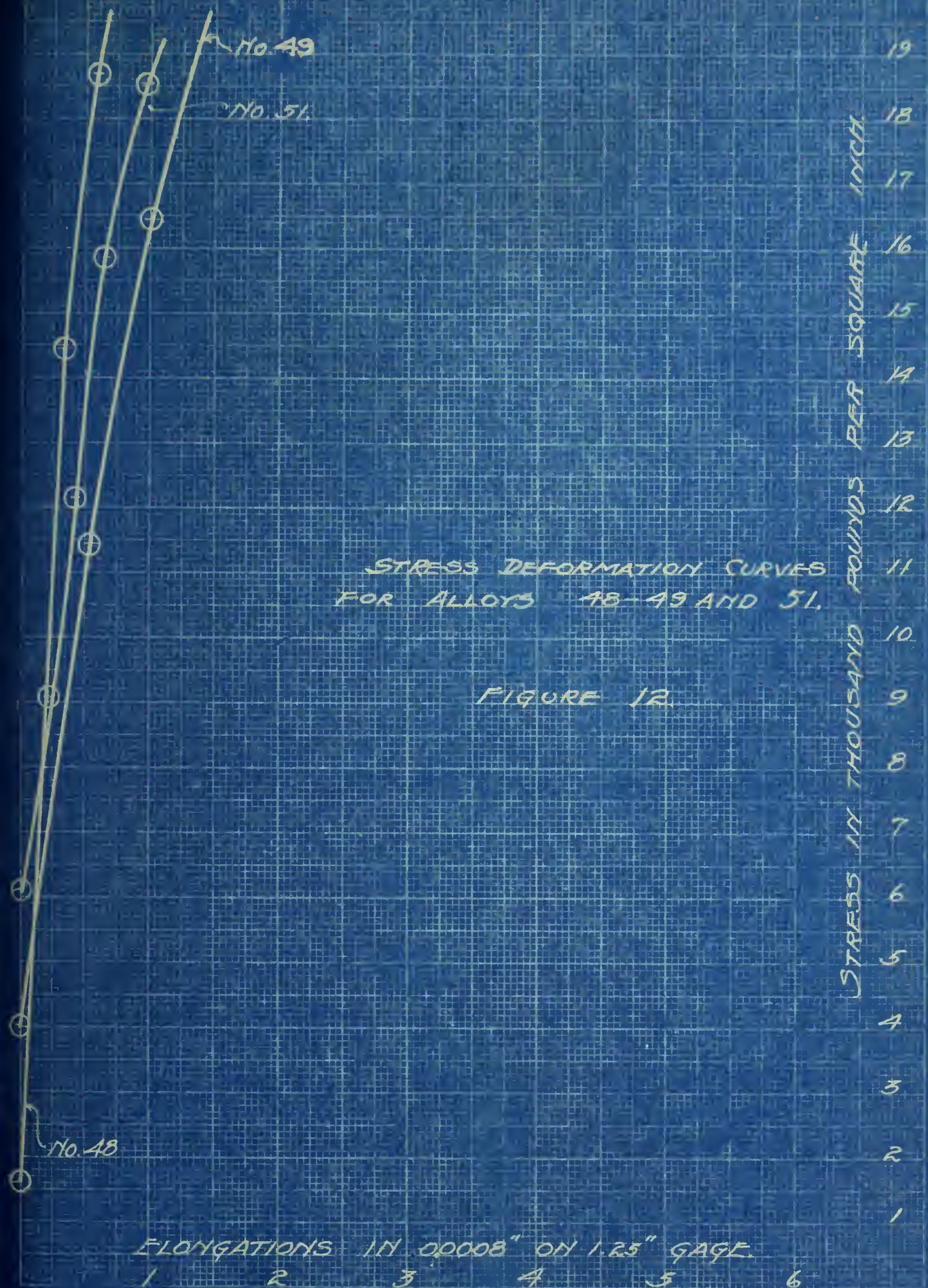
STRESS-DEFORMATION CURVES  
FOR ALLOYS 42 AND 44.

FIGURE 11.



LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS







LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS

## V. RELATIVE ELECTROMOTIVE FORCES OF THE ALLOYS IN CONTACT WITH ELECTROLYTES.

1. Purpose of Measurements. The different alloys and metals which were to be included in the corrosion tests seemed to offer a good set of specimens for use in an attempt to establish some relation between their relative electromotive forces and their resistance to corrosion. Chromium and nickel are located on one side of hydrogen in the electromotive series and copper on the other. In the following experiments an attempt was made to see if any relation could be found between the measurements of the relative electromotive forces produced by placing the alloy in contact with an electrolyte and the relative powers of the alloys to resist corrosion.

2. Experimental. The first apparatus used to measure the relative electromotive forces produced by contact between the different alloys and an electrolyte was quite simple. Two specimens were connected with the binding posts of a millivoltmeter, such as is used with thermocouples, and the circuit was completed by placing the specimens in contact with the electrolyte. The current produced could be read from the millivoltmeter. However, it was found that results could <sup>not</sup> be duplicated. For example, if two alloys were compared at one time the current might flow in one direction and later when it was desired to repeat the measurements the current might flow in the opposite direction. Even when the two specimens had been cut from the same casting a current was produced. After working with different concentrations of sodium



chloride, hydrochloric acid, and sulfuric acid, and after numerous attempts to get consistent results by using uniform specimens etc. the method was abandoned.

3. Poggendorf Compensation Method.\* The method consisted

---

\* Stahler, A. Handb. d. Arbeitsmeth. in der anorg. Chem. (1914) V. 3, p. 885.

---

in balancing the current from two No.6 French Auto Special Dry Batteries against the current from a calomel electrode and the alloy in contact with four normal salt solutions. The apparatus used in these measurements is shown in Fig.13. The resistance in the first circuit was 110 ohms and it was varied in the second circuit until the galvanometer showed a zero deflection. A voltmeter, reading 0 to 1.5 volts, was so connected that it showed directly the potential in the calomel electrode-alloy combination. In the different series of measurements all conditions remained the same except that different alloys were placed in the salt solution. Readings were taken at one minute intervals for five minutes and the results are shown in Table No.4. These values are not absolute but they are relative for they were made under the same conditions for all of the samples. The following factors seemed to influence the results: (a) The condition of the specimen as regards ~~to~~ polishing; (b) The depth to which the piece was immersed in the solution. This factor was active until the piece was at least one half covered and after that the value did not seem to change even upon complete immersion. (c) The time that the solution and specimen were left in contact had a very marked influence upon the values obtained, especially if any current was allowed to flow through the





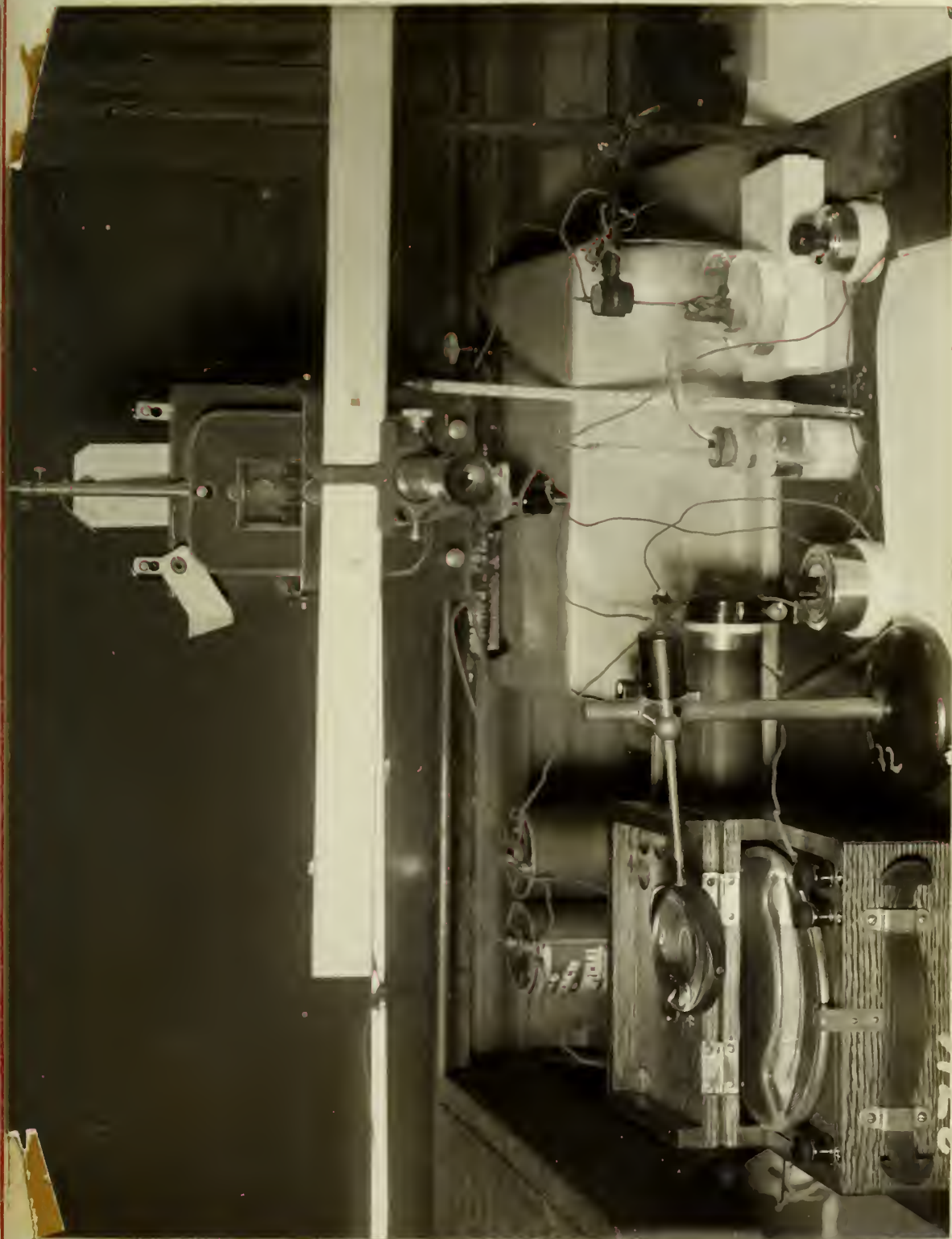


Fig.13. Apparatus used in Measuring the Relative Electromotive Forces of the Alloys in Contact with an Electrolyte.

LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS

system. It is believed that the above effect was caused by the deposition of gases upon the specimen or possibly by gases already dissolved in them. (d) Any moving of the specimen or solution caused fluctuations in values.

It was noticed that the alloys which contained high percentages of copper gave values which increased with time, while those containing high percentages of nickel gave values which decreased with time. These results with the composition of the alloys are shown diagrammatically in Fig. 14. Those alloys which showed an increase have been marked with a plus sign, and those which showed a decrease have been marked with a minus sign. Alloys Nos. 17, 18, and 19 seem irregular but they contained blow holes and if there was any concentration at the blow holes of the low melting constituent (copper) it might be expected that they would behave like the copper-rich alloys. No. 24 is the only one which did not show a change in the five minute interval, although the changes shown by some of the others were very small. An examination of the corrosion tables will show that the alloys which showed little or no change in relative electromotive force were not immune to corrosion in the different solutions. Therefore, it does not seem that resistance to corrosion can be predicted from the fact that the relative electromotive force of the alloy in contact with an electrolyte either remained constant or showed little variation.

In the case of the corrosions in normal salt solutions it was noticed that, almost without exception, the alloys which had shown an increase in the relative electromotive force were the ones which showed a turbidity of the corroding solution and those which had given decreasing values remained clear. Similarly in the

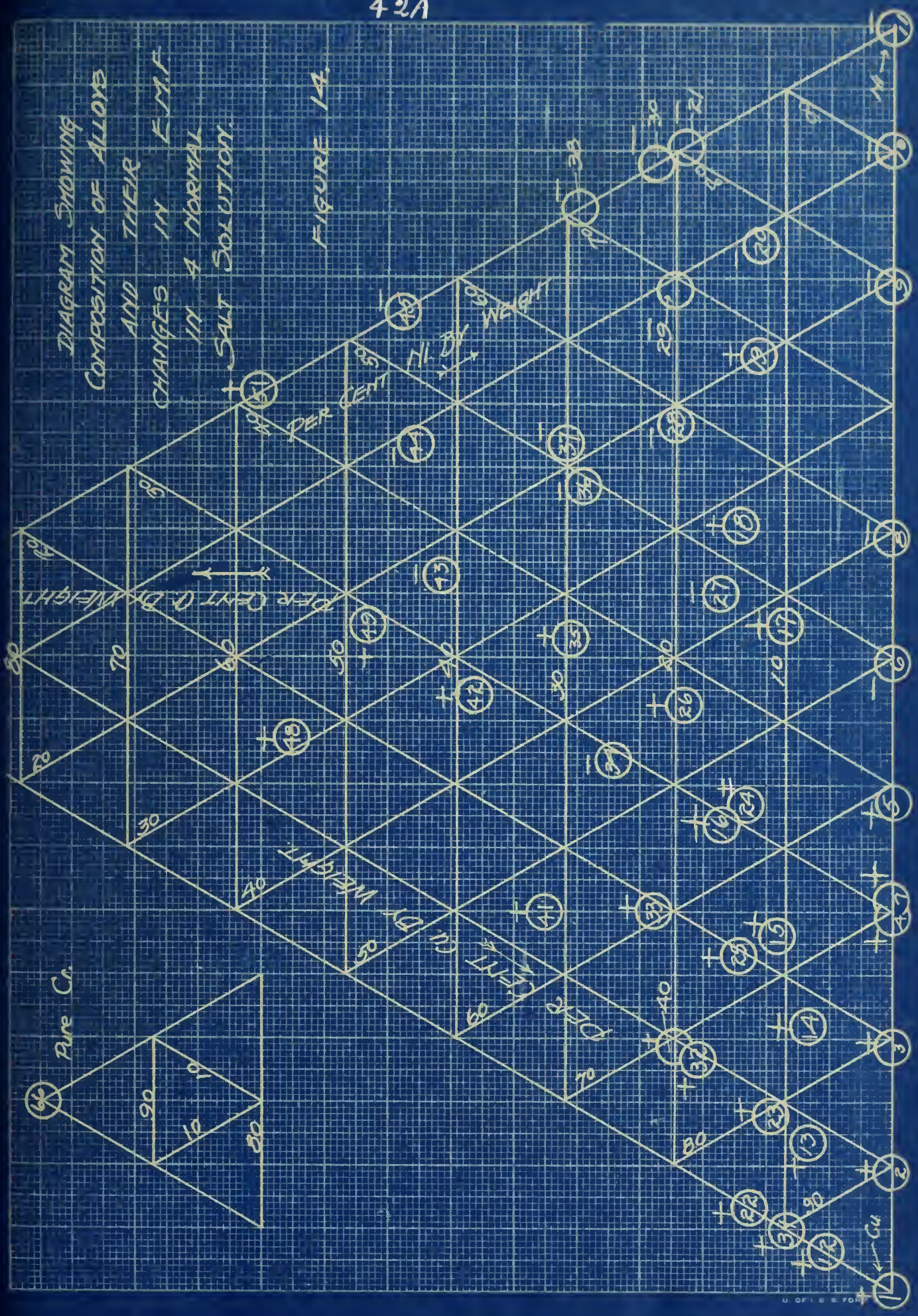






DIAGRAM SHOWING  
COMPOSITION OF ALLOYS  
AND THEIR  
CHANGES IN E.M.F.  
IN A NORMAL  
SALT SOLUTION.

FIGURE 14.





LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS

corrosions in ammonium hydroxide the solutions were colored a deep blue in the case of the alloys which had shown increases in the relative electromotive forces while the others remained practically colorless. However, when the corrosion specimens were weighed it was found that there had been losses in the salt solutions which had remained clear and in the ammonium hydroxide solutions which had remained colorless.

From the results obtained it is not felt that any safe conclusions can be drawn as to the possibility of predicting the corrodibility of an alloy from such a series of measurements of the relative electromotive forces or from the changes in these values with time.



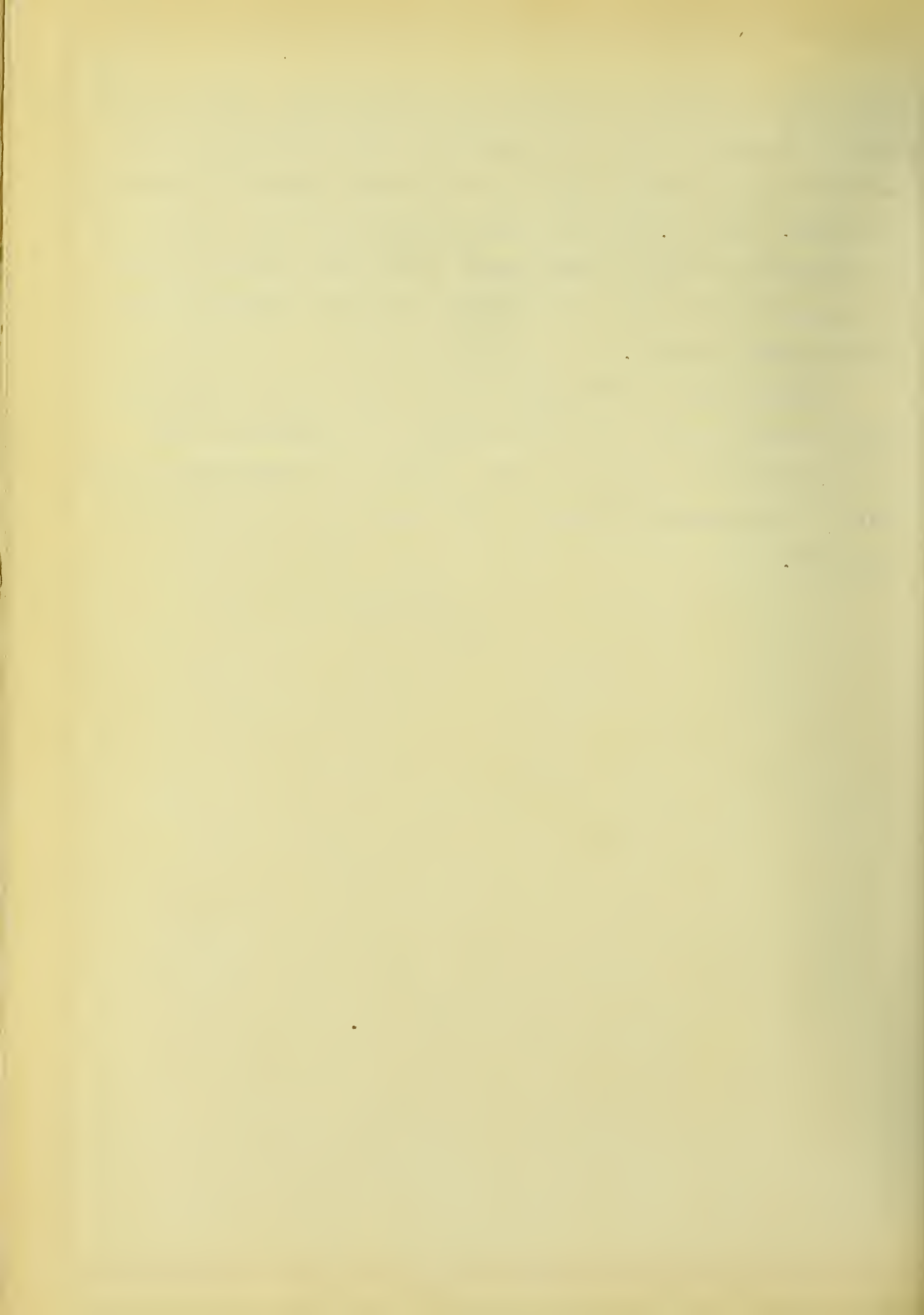


Table of Relative Electromotive Forces of the Different Alloys in Contact with 4 Normal Salt Solutions.

No.	Relative electromotive force after:					Change	Remarks
	1 min.	2 min.	3.min.	4 min.	5 min.		
1.					0.364		Increasing
2.	0.328	0.328	0.334	0.331	0.331	+ .003	
3.	0.328	0.330	0.331	0.333	0.334	+ .006	
4.	0.311	0.316	0.317	0.318	0.319	+ .009	
5.	0.314	0.318	0.315	0.318	0.315	+ .001	
6.	0.309	0.302	0.296	0.295	0.293	- .016	
7.	0.313	0.315	0.315	0.318	0.318	+ .005	
8.	0.305	0.300	0.300	0.297	0.296	- .009	
9.	0.295	0.295	0.290	0.280	0.280	- .015	
10.	0.318	0.309	0.300	0.294	0.289	- .029	
11.	0.294	0.294	0.290	0.287	0.287	- .007	Pure nickel
12.	0.338	0.341	0.345	0.346	0.348	+ .010	
13.	0.345	0.343	0.348	0.348	0.350	+ .005	
14.	0.340	0.341	0.341	0.339	0.339	- .001	
15.	0.348	0.345	0.344	0.342	0.341	- .007	
16.	0.342	0.336	0.333	0.332	0.330	- .012	
17.	0.310	0.309	0.306	0.306	0.304	- .006	
18.	0.307	0.304	0.303	0.303	0.303	- .004	
19.	0.306	0.312	0.315	0.316	0.318	+ .012	
20.	0.331	0.325	0.315	0.309	0.300	- .031	
21.	0.294	0.282	0.279	0.276	0.275	- .019	
22.	0.357	0.360	0.363	0.363	0.363	+ .006	
23.	0.345	0.347	0.348	0.349	0.349	+ .004	
24.	0.307	0.306	0.307	0.307	0.307	± .000	
25.	0.315	0.319	0.322	0.324	0.325	+ .010	



No.	Relative electromotive force after:					Change	Remarks
	1 min.	2 min.	3 min.	4 min.	5 min.		
26.	0.336	0.339	0.339	0.339	0.339	+ .003	
27.	0.330	0.326	0.320	0.320	0.320	- .010	
28.	0.355	0.344	0.339	0.332	0.330	- .025	
29.	0.360	0.349	0.341	0.338	0.332	-.028	
30.	0.325	0.320	0.329	0.331	0.324	- .001	
31.	0.339	0.340	0.345	0.346	0.349	+ .010	
32.	0.330	0.337	0.339	0.340	0.341	+ .011	
33.	0.341	0.347	0.346	0.346	0.346	+ .005	
34.	0.340	0.339	0.339	0.338	0.338	- .002	
35.	0.333	0.333	0.334	0.334	0.334	+ .001	
36.	0.334	0.330	0.329	0.320	0.320	- .014	
37.	0.332	0.330	0.320	0.319	0.315	- .017	
38.	0.316	0.310	0.305	0.300	0.296	- .020	
39.							Not prepared
40.	0.342	0.346	0.352	0.355	0.355	+ .013	
41.	0.350	0.351	0.352	0.355	0.355	+ .005	
42.	0.331	0.335	0.339	0.339	0.339	+ .008	
43.	0.366	0.365	-----	0.350	0.346	- .020	
44.	0.314	0.300	0.290	0.286	0.286	- .028	
45.	0.322	0.315	0.309	0.302	0.300	- .022	
46.							Not prepared
47.							Not prepared
48.	0.338	0.345	0.349	0.351	0.350	+ .012	
49.	0.345	0.347	0.349	0.349	0.349	+ .004	
50.	0.298	0.299	0.298	0.295	0.295	- .003	
51.	0.468	0.473	0.476	0.480	0.480	+ .012	

The other specimens have either not been prepared or have not been tested.



THE HISTORY OF THE CITY OF BOSTON, FROM THE FIRST SETTLEMENT TO THE PRESENT TIME.

1630	1631	1632	1633	1634	1635	1636
1637	1638	1639	1640	1641	1642	1643
1644	1645	1646	1647	1648	1649	1650
1651	1652	1653	1654	1655	1656	1657
1658	1659	1660	1661	1662	1663	1664
1665	1666	1667	1668	1669	1670	1671
1672	1673	1674	1675	1676	1677	1678
1679	1680	1681	1682	1683	1684	1685
1686	1687	1688	1689	1690	1691	1692
1693	1694	1695	1696	1697	1698	1699
1700	1701	1702	1703	1704	1705	1706
1707	1708	1709	1710	1711	1712	1713
1714	1715	1716	1717	1718	1719	1720
1721	1722	1723	1724	1725	1726	1727
1728	1729	1730	1731	1732	1733	1734
1735	1736	1737	1738	1739	1740	1741
1742	1743	1744	1745	1746	1747	1748
1749	1750	1751	1752	1753	1754	1755
1756	1757	1758	1759	1760	1761	1762
1763	1764	1765	1766	1767	1768	1769
1770	1771	1772	1773	1774	1775	1776
1777	1778	1779	1780	1781	1782	1783
1784	1785	1786	1787	1788	1789	1790
1791	1792	1793	1794	1795	1796	1797
1798	1799	1800	1801	1802	1803	1804
1805	1806	1807	1808	1809	1810	1811
1812	1813	1814	1815	1816	1817	1818
1819	1820	1821	1822	1823	1824	1825
1826	1827	1828	1829	1830	1831	1832
1833	1834	1835	1836	1837	1838	1839
1840	1841	1842	1843	1844	1845	1846
1847	1848	1849	1850	1851	1852	1853
1854	1855	1856	1857	1858	1859	1860
1861	1862	1863	1864	1865	1866	1867
1868	1869	1870	1871	1872	1873	1874
1875	1876	1877	1878	1879	1880	1881
1882	1883	1884	1885	1886	1887	1888
1889	1890	1891	1892	1893	1894	1895
1896	1897	1898	1899	1900	1901	1902
1903	1904	1905	1906	1907	1908	1909
1910	1911	1912	1913	1914	1915	1916
1917	1918	1919	1920	1921	1922	1923
1924	1925	1926	1927	1928	1929	1930
1931	1932	1933	1934	1935	1936	1937
1938	1939	1940	1941	1942	1943	1944
1945	1946	1947	1948	1949	1950	1951
1952	1953	1954	1955	1956	1957	1958
1959	1960	1961	1962	1963	1964	1965
1966	1967	1968	1969	1970	1971	1972
1973	1974	1975	1976	1977	1978	1979
1980	1981	1982	1983	1984	1985	1986
1987	1988	1989	1990	1991	1992	1993
1994	1995	1996	1997	1998	1999	2000

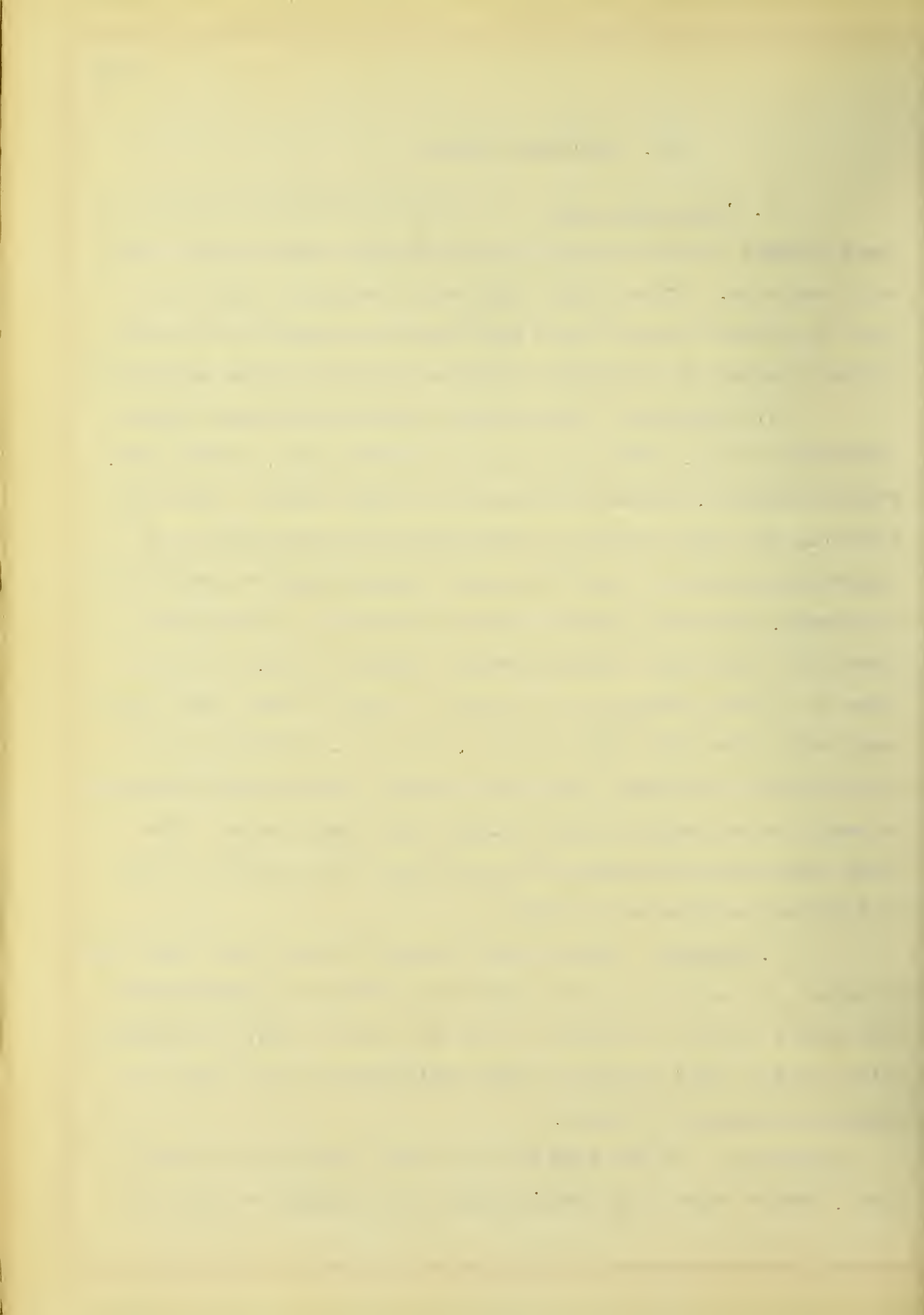
## VII. CORROSION TESTS.

1. Reason for Tests. In order to determine the power of the different alloys to resist corrosion over three hundred tests have been made. It was hoped that such a series of tests would show that some of these alloys were highly resistant to corrosion and were suited for industrial purposes requiring those properties.

2. Materials. The corroding reagents used were normal solutions of salt, hydrochloric acid, sulfuric acid, nitric acid, sodium hydroxide, ammonium hydroxide and fatty acids. The normal solutions had been carefully standardized and were known to be reasonably accurate. The fatty acids were secured from Swift & Co. of Chicago, and were listed as double distilled. An analysis showed that they had a mean molecular weight of 273, an iodine value of 72 and consisted of a mixture of fatty acids. The specimens used in the tests were usually about 5 mm. thick and about 15 to 20 mm. in diameter. They were ground and then polished about as smooth as was possible with No.000 Hubert Emery paper. The three metals were included in the tests with the alloys. In all 50 different samples were tested.

3. Methods. There does not seem to be any well established method for making corrosion tests and different investigators have used a variety of methods. For the work in hand, the scheme, which has been used has been pretty satisfactory and it will be described somewhat in detail.

Solutions:- In the case of the normal solutions mentioned above, 400 cc. were used for each test. No attempt was made to

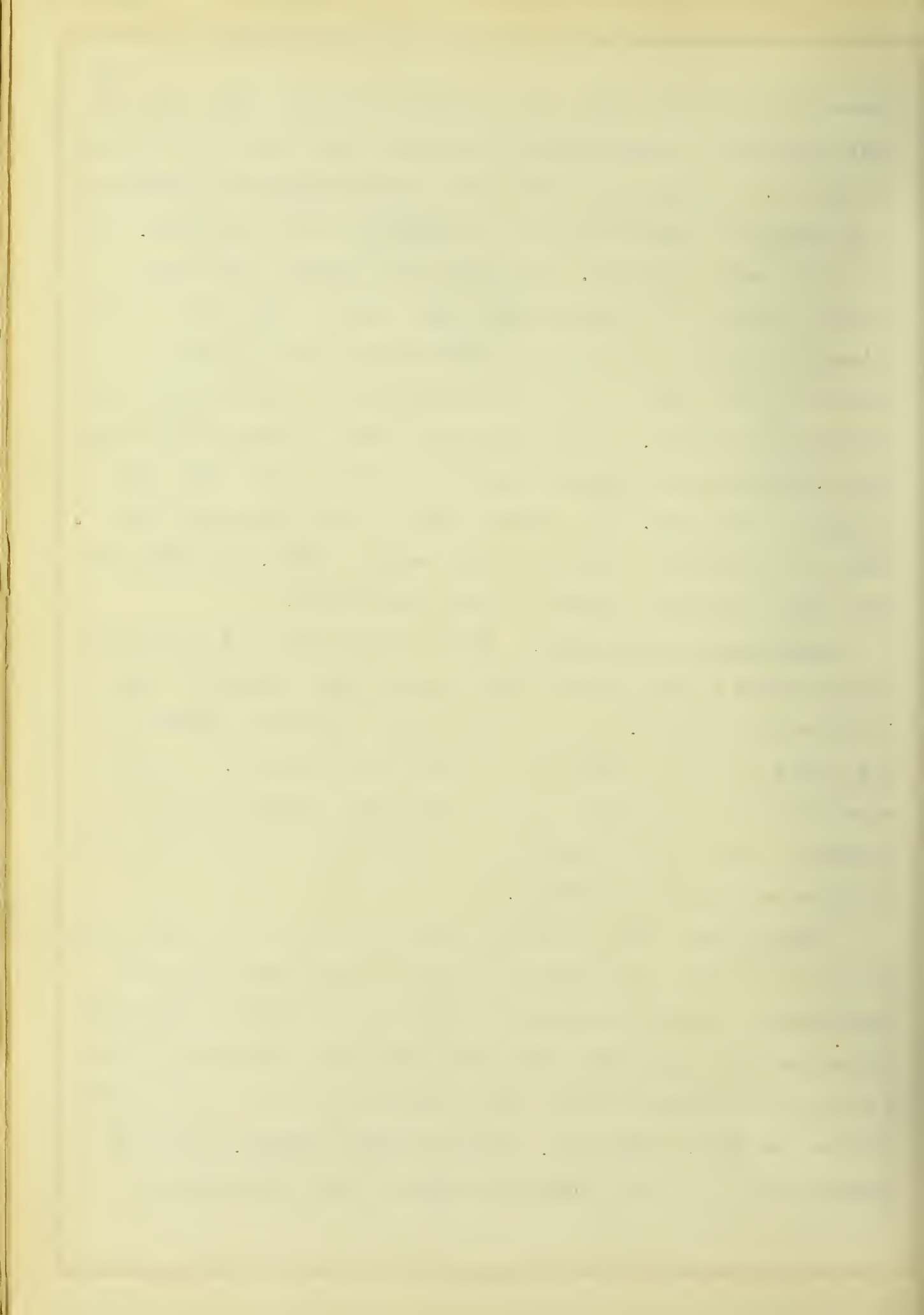


remove any dissolved gases, such as carbon dioxide. The solutions were contained in beakers of such size that they were filled almost to the top. Of course the solutions changed slightly in concentration because of evaporation and of corrosion of the specimens, but that could not be avoided. By covering the beakers with watch glasses the loss by evaporation was made small. With such a large volume of solution the change in concentration was not very important in most cases. If it was observed that a specimen was dissolving very rapidly, it was removed and from the amount which had been corroded a calculation was made to find how much would have corroded in one week. One hundred grams of the fatty acids were taken for each of the tests that were made at  $105^{\circ}\text{C}$ . and 200 grams were taken for those tests which were made at  $85^{\circ}\text{C}$ .

Suspending the Specimens:- Cotton thread was used to suspend the specimens in the alkaline solutions and wool thread was used in the acid solutions. The specimens were completely immersed in the liquid so that no part was in contact with the air. In some cases there was a tendency for the solutions to creep out of the beakers by way of the threads but that could be prevented by putting a little paraffin on the thread.

Temperature:- The corrosion tests were made at the temperature of the laboratory. In order to be able to approximate the mean temperature a maximum and minimum thermometer was kept on the desk where the tests were being made and it was read from time to time. A calculation showed that the mean temperature for the whole period of time was  $20^{\circ}\text{C}$ . Therefore, unless otherwise stated, it may be assumed that all of the tests were made at that temperature.



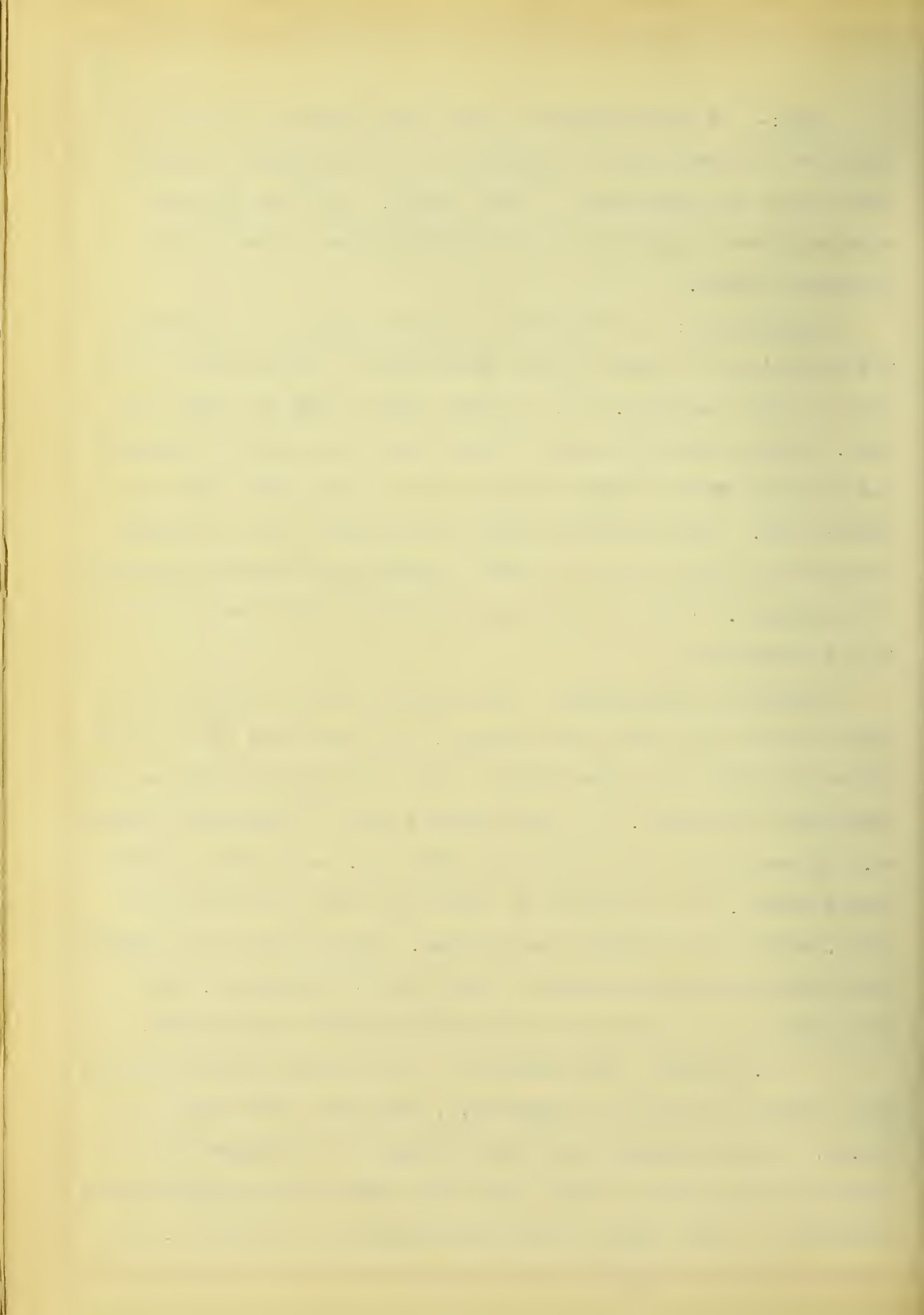


Time:- It was intended to leave the specimens in the solutions for one week but in some cases it was necessary to remove them before the expiration of that period. The time that the specimens were actually in the solution has been shown in the different tables.

Calculations:- The amount of surface exposed to corrosion was determined by measuring the thickness and the diameter of the piece to the nearest 0.1 mm. and then calculating the total surface. Unless there was known to have been a big loss in corrosion the surface was not recalculated when the piece was used for a second test. The results have been calculated to loss in weight per week per square inch of surface exposed and have been expressed in milligrams. The loss per square centimeter has also been given in the tabulations.

Accuracy of the Method:- The accuracy of the method has not been all that might have been desired. The specimens were weighed before and after the tests and the loss in weight was taken as the loss due to corrosion. In a few cases a gain in weight was observed. It was hard to get all of the salts etc. out of some of the porous pieces, but by boiling in distilled water and drying at  $100^{\circ}\text{C}$ . most of that trouble was avoided. While some of the results show irregularities and possibly could not be duplicated, as a whole they may be considered reasonably accurate and reliable.

4. Results. The results of the corrosion tests in normal salt solution are shown in Table No.5. They are also shown in Fig.15. In that diagram the loss in weight in milligrams per square inch per week is shown above the circle which represents the composition of the alloy as has been explained in Chapter V. It



is evident that the alloys near the copper corner of the triangle showed the largest losses.

Hydrochloric Acid:- The results from these tests are shown in Table No.6 and in Fig.16. It will be seen that all of the metals showed considerable corrosion in hydrochloric acid, and that chromium was especially soluble in this acid. However, there is a fairly well defined area in the triangle over which the corrosion was small.

Sulfuric Acid:- The data obtained from the corrosion tests in normal sulfuric acid are shown in Table No.7 and in Fig.17. The results do not seem to require any special explanation.

Nitric Acid:- Table No.8 and Fig.18 show the results of the corrosion tests in normal nitric acid. Nickel is especially soluble in nitric acid. In the chromium-nickel alloys there is a gradual decrease in the loss by corrosion as the per cent of chromium increases with an abrupt drop at No.45. There is also a change in the microscopic structure of the alloys in the same region. See microphotographs Nos.11, 21, 30, 38, and 45. Attention should be called to the fact that the area of lowest loss in corrosion is farther away from the nickel corner of the triangle this time.

Sodium Hydroxide:- Table No.9 and Fig.19 show the results obtained by the corrosion tests in normal sodium hydroxide. Copper and nickel show appreciable losses while chromium is little attacked. In general the losses for the alloys are small.

Ammonium Hydroxide:- The alloys which best resist corrosion by ammonia are near the nickel corner of the triangle and on the chromium-nickel side. The results are shown in Fig.20 and in



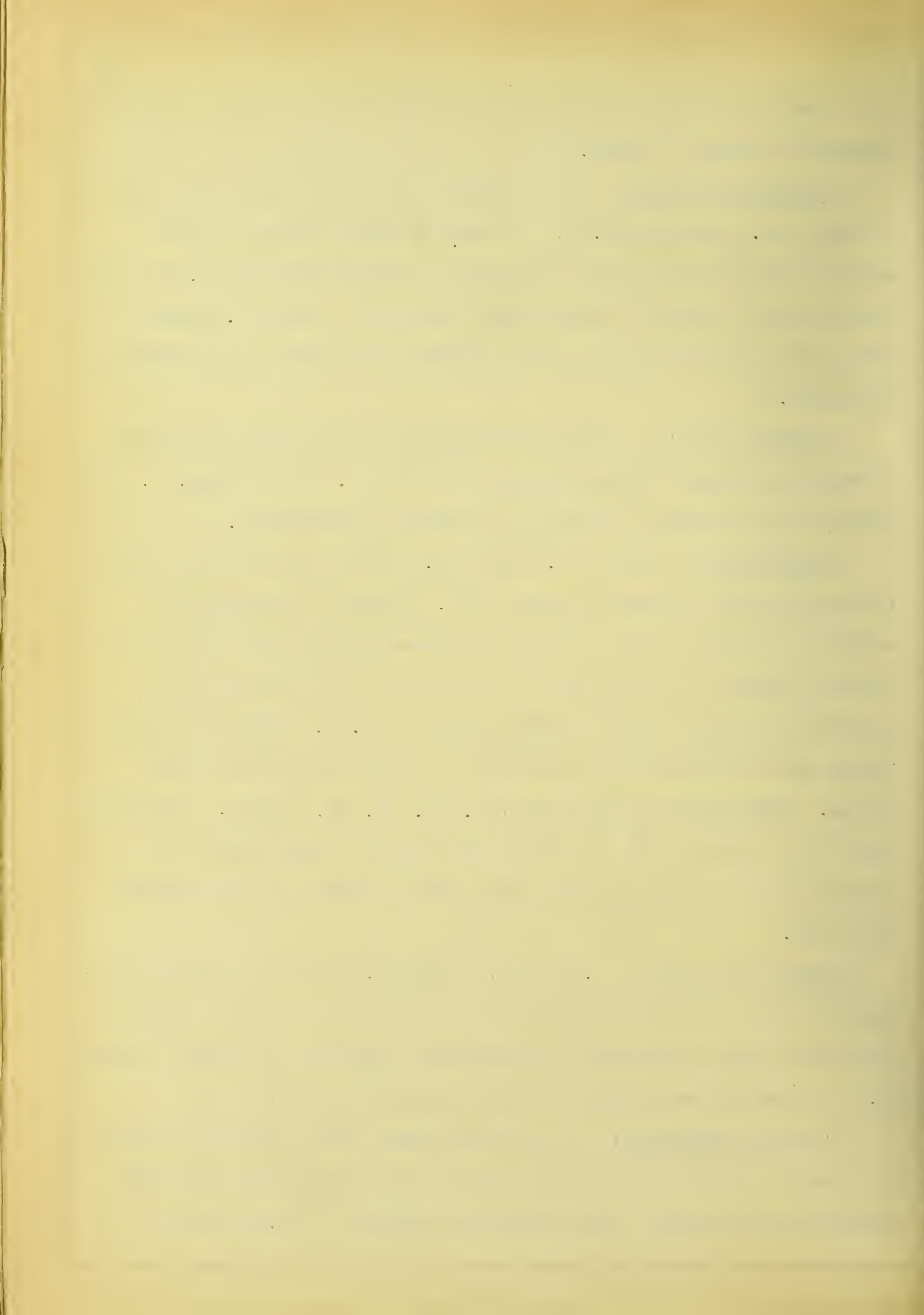


Table No.10. The copper-chromium and the copper-rich alloys seem to show a selective corrosion in ammonium hydroxide, i.e., the copper is removed and the chromium is left to some extent. That suggests that good results might be obtained by using ammonia as an etching reagent in the preparation of specimens for microscopic examination.

Fatty Acids:- Only 24 specimens were corroded in the fatty acids. Twelve of the tests were made at  $105^{\circ}\text{C}$ . by heating in an electric oven. The other tests were made at approximately  $85^{\circ}\text{C}$ . by heating on a water bath. The results are shown in Table No.11 and in Fig.21. The greatest losses are near the copper corner of the triangle. This suggests that instead of using a copper container for fatty acids it might be advisable to use an alloy of copper and nickel or possibly one containing copper and nickel with a little chromium.

Comparison of Corrosions:- Table No.12 shows the relative corrosions in the different reagents which have been used. The values are losses in weight in milligrams per square inch per week.

5. Conclusions. The corrosion tests show that the amount of loss in the different reagents is not proportional to the strengths of the different acids or bases.

So far, it has not been possible to show any definite relation between the relative electromotive forces and corrosion losses.

In all cases there are certain fairly well defined ranges of composition as shown in the diagrams in which the alloys are highly resistant to corrosion.

Generally the ternary alloys are less corroded than the binary, but there are some exceptions to this.

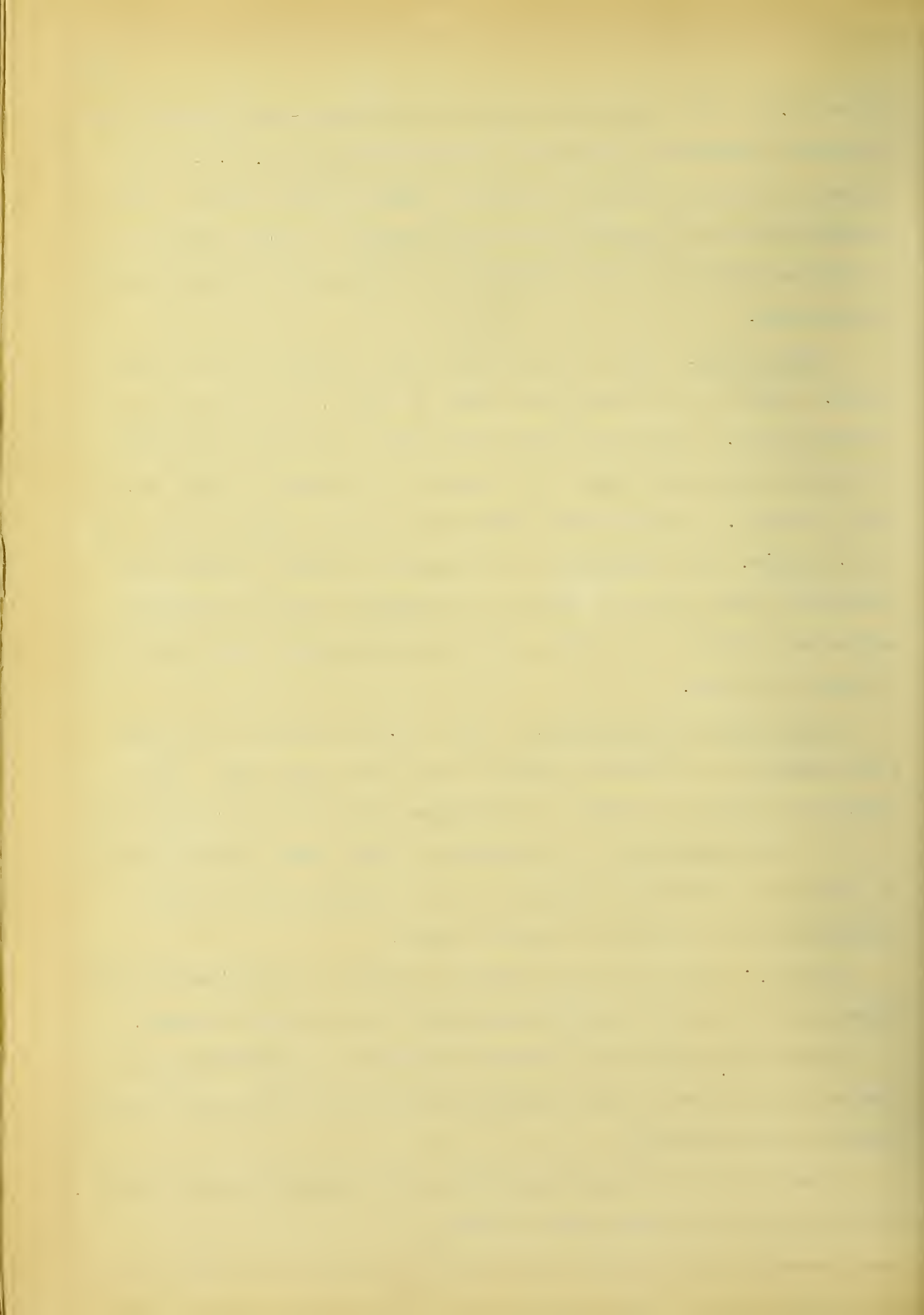


Table No.5

## CORROSION IN NORMAL SALT SOLUTION.

No.	Wt.be- fore	Wt.af- ter	Loss in wt. in mg.	Surface in sq.in. sq.cm.		Time in soln. hrs.	Loss in wt. in mg. per wk. sq.in. sq.cm.	
1.	5.1547	5.1514	3.3	0.65	4.18	168.	5.08	0.79
2.	8.5714	8.6671	4.3	1.03	6.67	168.	4.18	0.65
3.	5.6853	5.6842	1.1	0.68	4.41	168.	1.6	0.25
4.	4.5686	4.5676	1.0	0.61	3.95	168.	1.65	0.26
5.	4.5302	4.5287	1.5	0.64	4.12	168.	2.35	0.36
6.	4.6183	4.6168	1.5	0.63	4.04	168.	2.37	0.37
7.	16.9689	16.9663	2.6	1.52	9.83	168.	1.71	0.26
8.	9.7666	9.7656	1.0	1.28	8.29	168.	0.78	0.12
9.	13.5484	13.5459	2.5	1.46	9.44	168.	1.71	0.26
10.	10.1372	10.1358	1.4	1.24	7.98	168.	1.13	0.18
11.	10.6012	10.6034	2.2	1.38	8.93	168.	None.	
12.	11.8904	11.8837	6.7	1.33	8.58	191.	4.33	0.66
13.	13.2485	13.2446	3.9	1.35	8.69	191.	2.55	0.39
14.	10.0771	10.0746	2.5	1.16	7.47	191.	1.89	0.30
15.	8.4520	8.4502	1.8	1.03	6.66	191.	1.53	0.24
16.	7.4060	7.4052	0.8	1.07	6.94	191.	0.66	0.10
17.	12.9137	12.9125	0.8	1.32	8.51	191.	0.53	0.08
18.	10.6095	10.6085	1.0	1.24	7.98	191.	0.71	0.11
19.	14.3528	14.3517	1.1	1.54	9.92	191.	0.63	0.10
20.	10.7067	10.7059	0.8	1.18	7.61	191.	0.60	0.09
21.	13.2892	13.2893	None	1.47	9.43	191.	None	None
22.	9.1199	9.1150	4.9	1.07	6.91	192.	4.00	0.62
23.	9.1808	9.1765	4.3	1.03	6.67	192.	3.65	0.56
24.	10.6582	10.6571(?)	1.1	1.26	8.10	192.	0.76	0.12
25.	11.1721	11.1692	2.9	1.23	7.92	192.	2.13	0.32





Table No.5 continued

52.

No.	Wt.be- fore	Wt.af- ter	Loss in wt. in mg.	Surface in		Time in soln. hrs.	Loss in wt. in mg. per wk.	
				sq.in.	sq.cm.		sq.in.	sq.cm.
26.	13.1720	13.1705	1.5	1.39	8.95	192.	0.94	0.15
27.	9.7582	9.7570	1.2	1.08	7.00	219.	0.85	0.13
28.	9.8229	9.8224	0.5	1.17	7.56	192.	0.37	0.06
29.	8.0976	9.0970	0.6	1.03	6.65	192.	0.51	0.08
30.	Too many blow-holes.							
31.	11.2364	11.2304	6.0	1.16	7.46	188.	4.60	0.72
32.	12.2487	12.2436	5.1	1.38	8.92	188.	3.30	0.51
33.	9.7614	9.7576	3.8	1.29	8.33	188.	2.62	0.40
34.	11.6283	11.6262	2.1	1.37	8.82	188.	1.37	0.21
35.	8.9200	8.9186	1.4	1.18	7.62	188.	1.05	0.16
36.	9.6506	9.6501	0.5	1.20	7.73	188.	0.37	0.06
37.	10.8906	10.8910	Gain	1.31	8.43	188.	None	None
38.	9.2708	9.2703	0.5	1.18	7.62	188.	0.37	0.06
39.	Not prepared.							
40.	13.8038	13.7982	5.6	1.45	9.33	219.	2.95	0.46
41.	11.5522	11.5489	3.3	1.37	8.83	219.	1.84	0.29
42.	10.2162	10.2135	2.7	1.28	8.23	219.	1.67	0.25
43.	11.5757	11.5735	2.2	1.35	8.70	219.	1.25	0.19
44.	11.8330	11.8322	0.8	1.37	8.81	219.	0.45	0.07
45.	10.5548	10.5542	0.6	1.16	7.48	219.	0.40	0.06
46.	Not prepared.							
47.	Not prepared.							
48.	10.7737	10.7696	4.1	1.29	8.32	219.	2.45	0.38
49.	9.2240	9.2228	1.2	1.21	7.81	192.	0.87	0.13
50.	12.6623	12.6618	0.5	1.37	8.85	168.	0.37	0.06
51.	12.4773	12.4768	0.5	1.42	9.19	219.	0.27	0.04



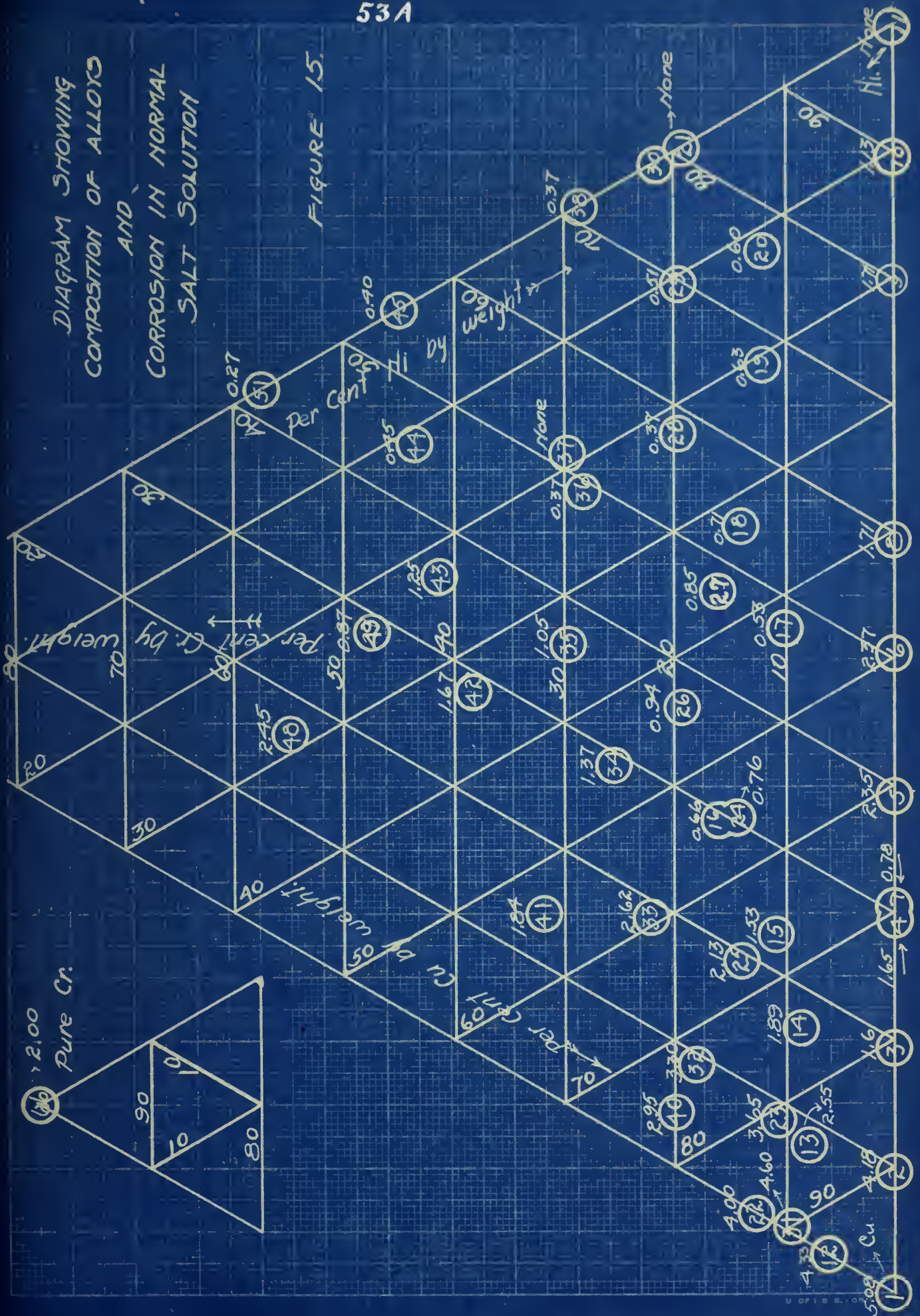
No.	Wt.be- fore	Wt.af- ter	Loss in wt. in mg.	Surface in		Time in soln. hrs.	Loss in wt.	
				sq.in.	sq.cm.		in mg. sq.in.	per wk. sq.cm.
55.	9.8019	9.8013	0.6	1.38	8.89	219.	0.33	0.05
56.	8.4790	8.4786	0.4	1.14	7.33	219.	0.27	0.04
66.	2.1721	2.1705	1.6	0.61	3.95	219.	2.00	0.31





DIAGRAM SHOWING  
COMPOSITION OF ALLOYS  
AND  
CORROSION IN NORMAL  
SALT SOLUTION

FIGURE 15.



LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS



## CORROSION IN NORMAL HYDROCHLORIC ACID

No.	Wt.be- fore	Wt.af- ter	Loss in wt. in mg.	Surface in sq.in. sq.cm.		Time in soln. hrs.	Loss in wt., in mg. per wk. sq.in. sq.cm.	
1.	5.5488	5.5267	22.1	0.71	4.58	116.	45.0	7.0
2.	8.6457	8.6315	14.2	1.03	6.67	116.	20.0	3.10
3.	5.6717	5.6555	16.2	0.68	4.41	116.	34.2	5.29
4.	4.5560	4.5436	12.4	0.61	3.95	116.	29.4	4.56
5.	4.5178	4.5064	11.4	0.64	4.12	116.	26.7	4.14
6.	4.6173	4.5981	9.2	0.63	4.04	116.	21.2	3.28
7.	16.9398	16.9032	24.1	1.52	9.83	116.	23.0	3.57
8.	11.3688	11.3621	6.7	1.36	8.77	116.	7.1	1.18
9.	9.8419	9.8274	14.5	1.28	8.27	116.	16.5	2.56
10.	10.1108	10.0952	15.6	1.24	7.98	116.	18.2	2.83
11.	10.0757	9.8877	188.	1.32	8.49	116.	207.	3.20
12.	11.8499	11.8099	40.0	1.33	8.58	118.	42.8	6.63
13.	13.2182	13.1910	27.2	1.35	8.69	118.	28.6	4.44
14.	10.0533	10.0478	5.5	1.16	7.47	118.	6.3	0.97
15.	8.4357	8.4322	3.5	1.03	6.66	118.	4.8	0.75
16.	7.3998	7.3953	4.5	1.07	6.94	118.	6.0	0.93
17.	12.8937	12.8892	4.3	1.32	8.51	118.	4.6	0.72
18.	10.5919	10.5848	7.1	1.24	7.98	118.	8.2	1.27
19.	14.3327	14.3248	7.9	1.54	9.92	118.	7.3	1.13
20.	10.7001	10.6912	8.9	1.18	7.61	118.	10.7	1.66
21.	13.2805	13.2604	20.1	1.47	9.43	118.	19.4	3.01
22.	9.0873	9.0585	28.8	1.07	6.91	118.	38.3	5.93
23.	9.1666	9.1453	21.3	1.03	6.67	118.	29.5	4.57
24.	9.1816	9.1504	31.2	1.09	7.03	144.	33.3	5.17
25.	11.1641	11.1570	7.1	1.23	7.92	118.	8.2	1.27





Table No.6 continued

No.	Wt.be- fore	Wt.af- ter	Loss in wt. in mg.	Surface in sq.in. sq.cm.		Time in soln. hrs.	Loss in wt. in mg. per wk. sq.in. sq.cm.	
26.	13.1654	13.1594	6.0	1.39	8.95	118.	6.2	0.96
27.	9.7469	9.7353	11.6	1.08	7.00	96.	18.8	2.90
28.	9.8176	9.8140	3.6	1.17	7.56	118.	4.4	0.68
29.	8.0894	8.0850	4.4	1.03	6.65	118.	6.1	0.94
30.	Too many holes.							
31.	11.2031	11.1828	20.3	1.16	7.46	97.	30.3	4.69
32.	12.2174	12.2093	8.1	1.38	8.92	97.	10.8	1.67
33.	9.7497	9.7460	3.7	1.29	8.33	97.	5.0	0.77
34.	11.6190	11.6138	5.2	1.37	8.82	97.	6.6	1.02
35.	8.9073	8.8989	8.4	1.18	7.62	97.	12.3	1.91
36.	9.6441	9.6361	8.0	1.20	7.73	97.	11.6	1.79
37.	10.8887	10.8842	4.5	1.31	8.43	97.	5.9	0.92
38.	9.2655	9.2600	5.5	1.18	7.62	97.	8.1	1.25
39.	Not prepared.							
40.	13.7719	13.7593	12.6	1.45	9.33	96.	15.2	2.36
41.	11.5283	11.5224	5.9	1.37	8.83	96.	7.5	1.17
42.	10.1994	10.1910	8.4	1.28	8.23	96.	11.5	1.78
43.	11.5628	11.5474	14.4	1.35	8.70	96.	18.6	2.88
44.	11.8304	11.8226	7.8	1.37	8.81	96.	10.0	1.55
45.	10.5517	10.5377	14.0	1.16	7.48	96.	21.2	3.27
46.	Not prepared.							
47.	Not prepared.							
48.	10.7507	10.7398	11.9	1.29	8.32	96.	16.2	2.83
49.	9.2160	9.1910	8.1	1.21	7.81	118.	9.5	1.48
50.	10.4497	10.4352	14.3	1.28	8.23	96.	19.5	3.03
51.	12.4763	12.4458	25.3	1.42	9.19	96.	31.2	4.84



Table No.6 continued

56.

No.	Wt.be- fore	Wt.af- ter	Loss in wt. in mg.	Surface in sq.in. sq.cm.	Time in soln. hrs.	Loss in wt. in mg. per wk. sq.in. sq.cm.
55.	9.7962	9.7868	9.4	1.38 8.89	96.	11.9 1.84
56.	8.4771	8.4553	21.8	1.14 7.33	96.	32.2 5.0
66.	2.1699	0.9370	1232.9	0.61 3.95	20.	16976.4 2631.34



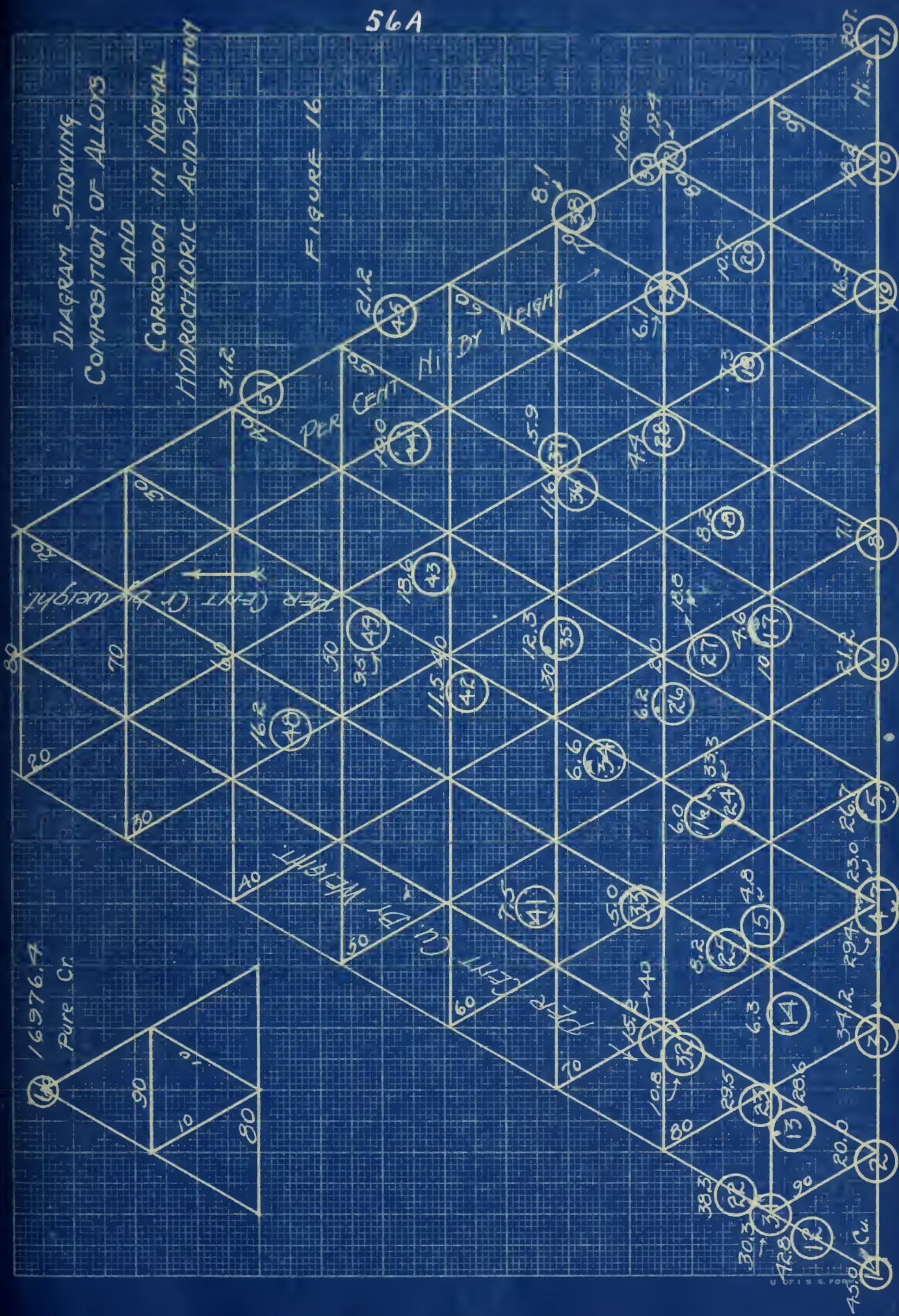


# DIAGRAM SHOWING COMPOSITION OF ALLOYS

AND

CORROSION IN NORMAL  
HYDROCHLORIC ACID SOLUTION

FIGURE 16





LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS

Table No.7

No.	Wt.be- fore	Wt.af- ter	Loss in wt. in mg.	Surface sq.in.	in sq.cm.	Time in soln. hrs.	Loss in wt. in mg. per wk. sq.in. sq.cm.	
1.	5.5781	5.5525	25.6	0.71	4.58	168.	31.0	5.60
2.	8.6659	8.6457	20.2	1.03	6.67	168.	19.5	3.02
3.	5.6842	5.6717	12.5	0.68	4.41	168.	18.4	2.83
4.	4.5676	4.5560	11.6	0.61	3.95	168.	19.0	2.93
5.	4.5287	4.5178	10.9	0.64	4.12	168.	17.0	2.64
6.	4.6168	4.6073	9.5	0.63	4.04	168.	15.1	2.35
7.	16.9663	16.9398	26.5	1.52	9.83	168.	17.4	2.68
8.	11.3951	11.3688	26.3	1.36	8.77	168.	19.3	2.98
9.	9.8569	9.8419	15.0	1.28	8.27	168.	11.7	1.84
10.	10.1312	10.1108	20.4	1.24	7.98	168.	16.4	2.54
11.	10.1014	10.0757	25.7	1.32	8.49	168.	19.4	3.02
12.	11.8726	11.8499	22.7	1.33	8.58	168.	17.2	2.64
13.	13.2383	13.2182	20.1	1.35	8.69	168.	14.9	2.31
14.	10.0671	10.0533	13.8	1.16	7.47	168.	11.9	1.85
15.	8.4502	8.4357	14.5	1.03	6.66	168.	14.0	2.17
16.	7.4052	7.3998	5.4	1.07	6.94	168.	5.1	0.78
17.	12.9125	12.8936	8.9	1.32	8.51	168.	6.7	1.05
18.	10.6085	10.5919	6.6	1.24	7.98	168.	5.3	0.83
19.	14.3517	14.3327	19.0?	1.54	9.92	168.	12.3	1.91
20.	10.7059	10.7001	5.8	1.18	7.61	168.	4.9	0.78
21.	13.2893	13.2805	8.8	1.47	9.43	168.	6.0	0.93
22.	9.1025	9.0873	15.2	1.07	6.91	168.	14.2	2.20
23.	10.9076	10.8867	19.1	1.32	8.52	168.	14.5	2.25
24.	10.6571	10.6457	11.4	1.26	8.10	168.	9.0	1.41
25.	11.1692	11.1641	5.1	1.23	7.92	168.	4.1	0.64
26.	13.1705	13.1654	5.1	1.39	8.95	168.	3.7	0.51





No.	Wt.be- fore	Wt.af- ter	Loss in wt. in mg.	Surface in		Time in soln. hrs.	Loss in wt. in mg. per wk.	
				sq.in.	sq.cm.		sq.in.	sq.cm.
27.	9.7570	9.7469	10.1	1.08	7.00	168.	9.4	1.44
28.	9.8224	9.8176	4.8	1.17	7.56	168.	4.1	0.64
29.	8.0970	8.0894	7.6	1.03	6.65	168.	7.4	1.24
30.	Too many holes.							
31.	11.2222	11.2031	19.1	1.16	7.46	168.	16.4	2.56
32.	12.2389	12.2174	21.5	1.38	8.92	168.	15.6	2.42
33.	9.7576	9.7497	7.9	1.29	8.33	168.	6.1	0.95
34.	11.6262	11.6190	7.2	1.37	8.82	168.	5.3	0.82
35.	8.9186	8.9073	11.3	1.18	7.62	168.	9.6	1.48
36.	9.6501	9.6441	6.1	1.20	7.73	168.	5.1	0.79
37.	10.8910	10.8887	2.3	1.31	8.43	168.	1.8	0.27
38.	9.2703	9.2655	4.8	1.18	7.62	168.	4.1	0.63
39.	Not prepared.							
40.	13.7920	13.7719	20.1	1.45	9.33	168.	14.9	2.15
41.	11.5453	11.5283	17.0	1.37	8.83	168.	12.4	1.92
42.	10.2135	10.1994	14.1	1.28	8.23	168.	11.0	1.74
43.	11.5735	11.5628	10.7	1.35	8.70	168.	8.0	1.23
44.	11.8322	11.8304	1.8	1.37	8.81	168.	1.3	0.20
45.	10.5542	10.5517	2.5	1.16	7.48	168.	2.2	0.36
46.	Not prepared.							
47.	Not prepared.							
48.	10.7677	10.7507	17.0	1.29	8.32	168.	13.2	2.04
49.	9.2228	9.2160	6.8	1.21	7.81	168.	5.6	0.87
50.	10.4583	10.4497	8.6	1.28	8.23	168.	6.4	1.04
51.	12.4768	12.4763	0.5	1.42	9.19	168.	0.35	0.05
55.	9.8013	9.7962	5.1	1.38	8.89	168.	3.7	0.57



TABLE NO.7 continued

59.

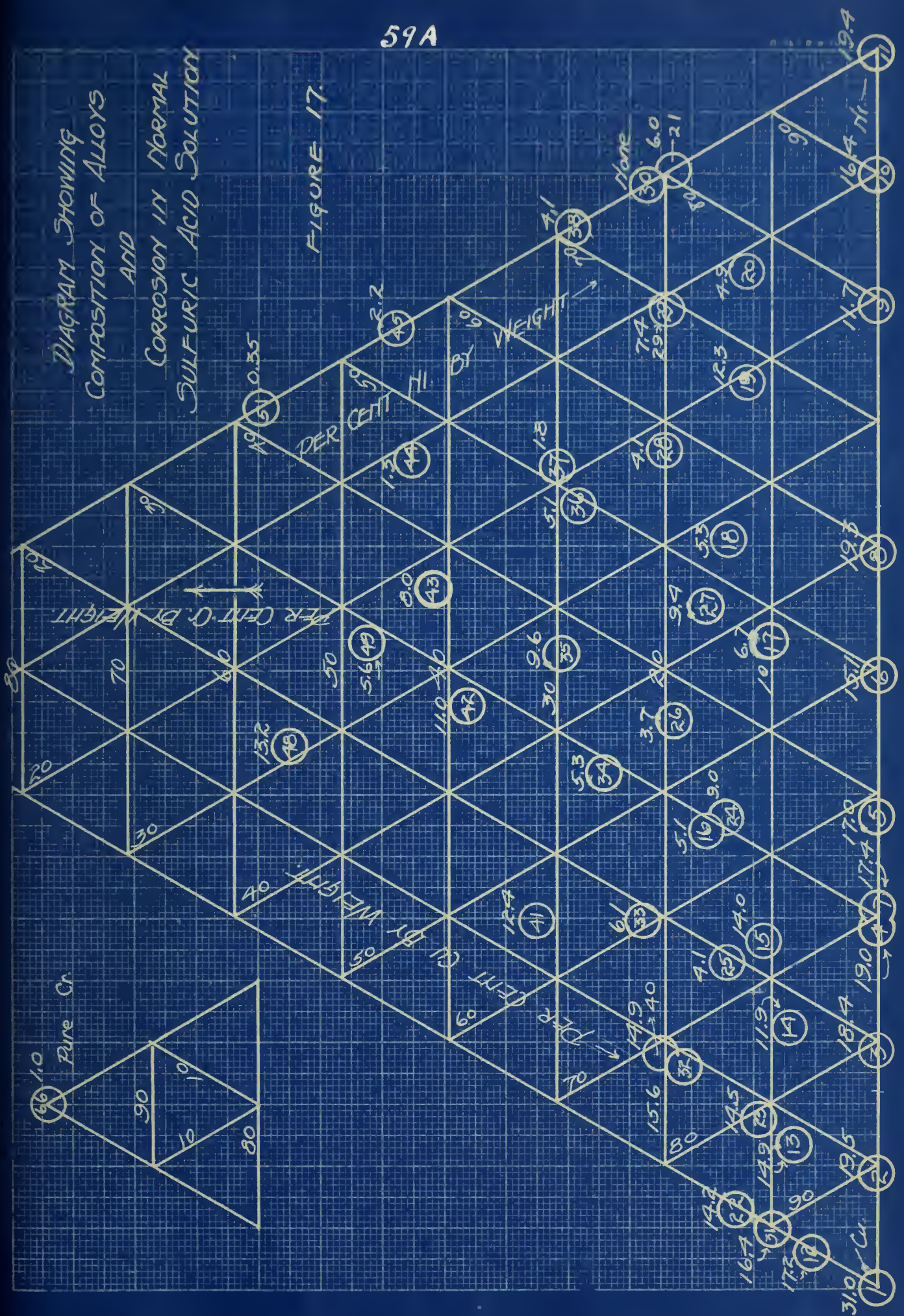
No.	Wt.be- fore	Wt.af- ter	Loss in wt. in mg.	Surface in sq.in. sq.cm.	Time in soln. hrs.	Loss in wt. in mg. per wk. sq.in. sq.cm.
56.	8.4786	8.4771	1.5	1.14 7.33	168.	1.3 0.20
66.	2.1705	2.1699	0.6	0.61 3.95	168.	1.0 0.15





DIAGRAM SHOWING  
COMPOSITION OF ALLOYS  
AND  
CORROSION IN NORMAL  
SULFURIC ACID SOLUTION

FIGURE 17.



LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS



## CORROSION IN NORMAL NITRIC ACID.

No.	Wt.be- fore	Wt.af- ter	Loss in wt. in mg.	Surface in sq.in.	sq.cm.	Time in soln. hrs.	Loss in wt. in mg. per wk. sq.in. sq.cm.
1.	5.5125	5.4945	18.0	0.71	4.58	138.	30.8 4.78
2.	8.6232	8.5882	35.0	1.03	6.67	138.	41.4 6.42
3.	5.6478	5.6323	15.5	0.68	4.41	138.	27.7 4.30
4.	4.5331	4.5205	12.6	0.61	3.95	138.	25.1 3.88
5.	4.5007	4.4898	10.9	0.64	4.12	138.	21.4 3.33
6.	4.5918	4.5859	5.9	0.63	4.04	138.	11.4 1.77
7.	16.9032	16.8890	14.2	1.52	9.83	138.	11.4 1.77
8.	11.3342	11.3092	25.0	1.36	8.77	138.	22.4 3.47
9.	9.8259	9.8086	14.5	1.28	8.27	138.	14.8 2.13
10.	10.0842	10.0724	11.8	1.24	7.98	138.	11.6 1.80
11.	9.8700	9.4410	429.0	1.32	8.49	24.	2270. 352.0
12.	11.7920	11.7783	13.7	1.33	8.58	137.	12.6 1.98
13.	13.1763	13.1647	11.6	1.35	8.69	137.	10.4 1.62
14.	10.0412	10.0310	10.2	1.16	7.47	137.	10.8 1.67
15.	8.4206	8.4123	8.3	1.03	6.66	137.	9.9 1.53
16.	7.3881	7.3807	7.4	1.07	6.94	137.	8.5 1.32
17.	12.8800	12.8684	11.6	1.32	8.51	137.	10.8 1.67
18.	10.5626	10.5474	15.2	1.24	7.98	137.	15.1 2.33
19.	14.3148	14.2931	21.7	1.54	9.92	137.	17.2 2.67
20.	10.6661	10.6490	17.1	1.18	7.61	137.	17.8 2.76
21.	13.2433	12.8326	410.7	1.47	9.43	48.	980.0 152.0
22.	9.0392	9.0390	10.2	1.07	6.91	122.	13.1 2.03
23.	9.1265	9.1151	11.4	1.03	6.67	122.	16.3 2.22
24.	10.5944	10.5821	12.3	1.26	8.10	122.	13.4 2.08
25.	11.1470	11.1376	9.4	1.23	7.92	122.	10.5 1.63





Table No.8 continued

61.

No.	Wt.be- fore	Wt.af- ter	Loss in wt. in mg.	Surface sq.in.	Surface in sq.cm.	Time in soln. hrs.	Loss in mg. sq.in.	Loss in wt. per wk. sq.cm.
26.	13.1489	13.1412	7.7	1.39	8.95	122.	7.6	1.18
27.	9.7288	9.7222	6.6	1.08	7.00	168.	6.2	0.95
28.	9.8098	9.7948	15.0	1.17	7.56	122.	17.7	2.74
29.	8.0788	8.0655	13.3	1.03	6.65	122.	18.1	2.80
30.	Too many holes.							
31.	11.1653	11.0955	69.8	1.16	7.46	168.	60.3	9.35
32.	12.1926	12.1777	14.9	1.38	8.92	168.	10.8	1.67
33.	9.7367	9.7270	9.7	1.29	8.33	168.	7.5	1.16
34.	11.6059	11.5994	6.5	1.37	8.82	168.	4.8	0.74
35.	8.8904	8.8847	5.7	1.18	7.62	168.	4.8	0.74
36.	9.6290	9.6241	5.9	1.20	7.73	168.	4.9	0.76
37.	10.8796	10.8738	5.8	1.31	8.43	168.	4.9	0.76
38.	9.2554	9.0129	242.5	1.18	7.62	70.	492.0	76.0
39.	Not prepared.							
40.	13.7427	13.7295	13.2	1.45	9.33	168.	9.2	1.43
41.	11.5077	11.4963	11.4	1.37	8.83	168.	8.3	1.29
42.	10.1818	10.1725	9.3	1.28	8.23	168.	7.3	1.13
43.	11.5401	11.5341	6.0	1.35	8.70	168.	4.4	0.69
44.	11.8160	11.8146	1.4	1.37	8.81	168.	1.02	0.16
45.	10.5332	10.5325	0.7	1.16	7.48	168.	0.60	0.09
46.	Not prepared.							
47.	Not prepared.							
48.	10.7279	10.7154	12.5	1.29	8.32	168.	9.7	1.50
49.	9.1910	9.1854	5.6	1.21	7.81	122.	6.4	0.99
50.	10.4293	10.4198	9.5	1.28	8.23	168.	7.4	1.15
51.	12.4458	12.4458	0.0	1.42	9.19	168.	0.0	0.00
55.	9.7665	9.7559	10.6	1.38	8.89	168.	7.7	1.19



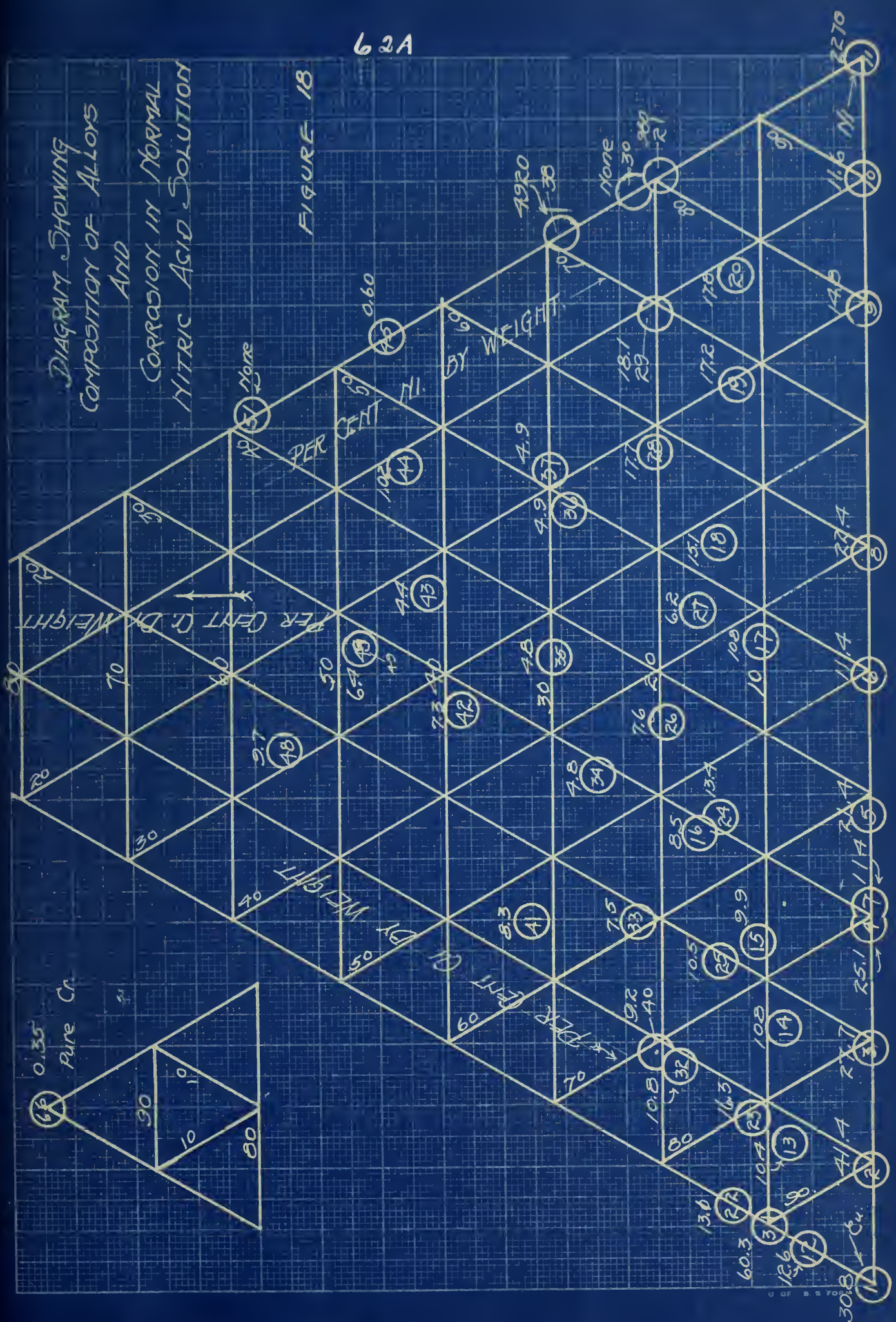
No.	Wt.be- fore	Wt.af- ter	Loss in wt. in mg.	Surface in		Time in soln. hrs.	Loss in wt.	
				sq.in.	sq.cm.		in mg. per wk. sq.in. sq.cm.	
56.	8.4517	8.4513	0.4	1.14	7.33	168.	0.35	0.05
66.	2.0776	2.0774	0.2	0.57	3.66	168.	0.35	0.05





DIAGRAM SHOWING  
COMPOSITION OF ALLOYS  
AND  
CORROSION IN NORMAL  
NITRIC ACID SOLUTION

FIGURE 18



LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS



## CORROSION IN NORMAL SODIUM HYDROXIDE

No.	Wt.be- fore	Wt.af- ter	Loss in wt. in mg.	Surface in sq.in.	sq.cm.	Time in soln. hrs.	Loss in wt. in mg. per wk. sq.in. sq.cm.
1.	5.4846	5.4740	10.6	0.71	4.58	168.	15.0 2.26
2.	8.5781	8.5720	6.1	1.03	6.67	168.	5.9 0.91
3.	5.6266	5.6267	-0.1	0.68	4.41	168.	Small gain.
4.	4.5122	4.5123	-0.1	0.61	3.95	168.	Small gain.
5.	4.4778	4.4777	0.1	0.64	4.12	168.	0.16 0.03
6.	4.5811	4.5810	0.1	0.63	4.04	168.	0.16 0.03
7.	16.8732	16.8730	0.2	1.52	9.83	168.	0.13 0.02
8.	11.2955	11.2940	1.5	1.36	8.77	168.	1.1 0.17
9.	9.7911	9.7878	3.3	1.28	8.27	168.	2.6 0.40
10.	10.0627	10.0523	0.4	1.24	7.98	168.	0.32 0.05
11.	9.3981	9.3734	24.7	1.32	8.49	168.	18.7 2.90
12.	11.7690	11.7552	13.8	1.33	8.58	168.	10.4 1.61
13.	13.1477	13.1388	8.9	1.35	8.69	168.	6.6 1.02
14.	10.0186	10.0183	0.3	1.16	7.74	168.	0.26 0.04
15.	8.4028	8.4027	0.1	1.03	6.66	168.	0.1 0.02
16.	7.3745	7.3745	0.0	1.07	6.94	168.	0.0 0.0
17.	12.8598	12.8598	0.0	1.32	8.51	168.	0.0 0.0
18.	10.5425	10.5393	3.2	1.24	7.98	168.	2.6 0.40
19.	14.2842	14.2800	4.2	1.54	9.92	168.	2.7 0.42
20.	10.6391	10.6393	-0.2	1.18	7.61	168.	Small gain.
21.	12.5417	12.5384	4.0	1.47	9.43	168.	2.7 0.42
22.	9.0135	9.0033	10.2	1.07	6.91	168.	9.6 1.48
23.	9.0979	9.0927	5.2	1.03	6.67	168.	5.0 0.78
24.	10.5763	10.5782	-1.9	1.26	8.10	168.	Small gain.
25.	11.1265	11.1250	1.5	1.23	7.92	168.	1.2 0.19





Table No.9 continued

64.

No.	Wt.be- fore	Wt.af- ter	Loss in wt. in mg.	Surface sq.in.	in sq.cm.	Time in soln. hrs.	Loss in wt. in mg. per wk. sq.in. sq.cm.
26.	13.1311	13.1309	0.2	1.39	8.95	168.	0.14 0.02
27.	9.7222	9.7223	-0.1	1.08	7.00	168.	Small gain.
28.	9.7886	9.7886	0.0	1.17	7.56	168.	0.0 0.0
29.	8.0615	8.0615	0.0	1.03	6.65	168.	0.0 0.0
30.	Too many holes.						
31.	11.0646	11.0636	1.0	1.16	7.46	168.	0.86 0.13
32.	12.1670	12.1575	9.5	1.38	8.92	168.	6.9 1.07
33.	9.7165	9.7157	0.8	1.29	8.33	168.	0.64 0.10
34.	11.5994	11.5986	0.8	1.37	8.82	168.	0.58 0.09
35.	8.8847	8.8846	0.1	1.18	7.62	168.	0.09 0.01
36.	8.6241	8.6242	-0.1	1.20	7.73	168.	Small gain.
37.	10.8738	10.8734	0.4	1.31	8.43	168.	0.30 0.05
38.	9.0056	9.0056	0.0	1.18	7.62	168.	0.0 0.0
39.	Not prepared.						
40.	13.7056	13.6999	5.7	1.45	9.33	168.	3.9 0.62
41.	11.4807	11.4792	1.5	1.37	8.83	168.	1.1 0.17
42.	10.1725	10.1712	1.3	1.28	8.23	168.	1.0 0.16
43.	11.5341	11.5339	0.2	1.35	8.70	168.	0.15 0.02
44.	11.8146	11.8143	0.3	1.37	8.81	168.	0.22 0.03
45.	10.5325	10.5319	0.6	1.16	7.48	168.	0.53 0.08
46.	Not prepared.						
47.	Not prepared.						
48.	10.7029	10.6955	7.4	1.29	8.32	168.	5.7 0.89
49.	9.1819	9.1816	0.3	1.21	7.81	168.	0.25 0.04
50.	10.4198	10.4185	1.3	1.28	8.23	168.	1.0 0.16
51.	12.4458	12.4456	0.2	1.42	9.19	168.	0.14 0.02



No.	Wt.be- fore	Wt.af- ter	Loss in wt. in mg.	Surface in		Time in soln. hrs.	Loss in wt.	
				sq.in.	sq.cm.		in mg. sq.in.	per wk. sq.cm.
55.	9.7559	9.7545	1.4	1.38	8.89	168.	1.0	0.16
56.	8.5413	8.5408	0.5	1.14	7.33	168.	0.44	0.07
66.	2.0774	2.0772	0.2	0.57	3.66	168.	0.35	0.06

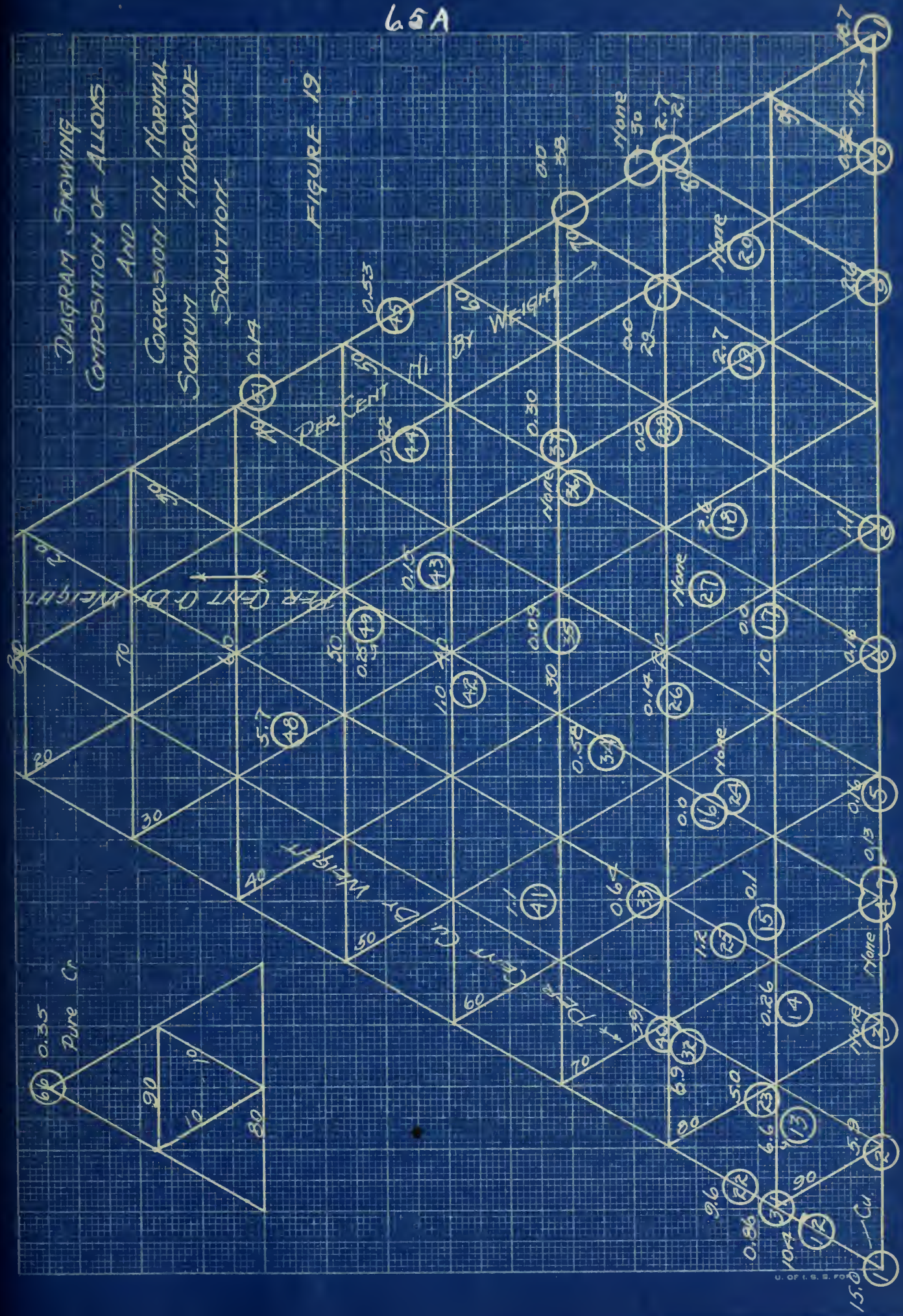






DIAGRAM SHOWING  
COMPOSITION OF ALLOYS  
AND  
CORROSION IN NORMAL  
SODIUM HYDROXIDE  
SOLUTION.

FIGURE 19





LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS

## CORROSION IN NORMAL AMMONIUM HYDROXIDE

No.	Wt.be- fore	Wt.af- ter	Loss in wt. in mg.	Surface in sq.in. sq.cm.	Time in soln. hrs.	Loss in wt. in mg. per wk. sq.in. sq.cm.
1.	5.4623	5.4524	9.9	0.71 4.58	56.	41.8 6.5
2.	8.5720	8.5560	16.0	1.03 6.67	56.	46.4 7.17
3.	5.6267	5.6162	10.5	0.68 4.41	56.	46.3 7.16
4.	4.5123	4.5147	7.6	0.61 3.95	56.	37.3 5.8
5.	4.4777	4.4737	4.0	0.64 4.12	56.	18.8 2.9
6.	4.5810	4.5810	0.0	0.63 4.04	56.	0.0 0.0
7.	16.8730	16.8560	17.0	1.52 9.83	56.	33.6 5.2
8.	11.2940	11.2930	1.0	1.36 8.77	56.	2.2 0.34
9.	9.7878	9.7813	6.5	1.28 8.27	56.	15.2 2.4
10.	10.0623	10.0619	0.4	1.24 7.98	56.	0.97 0.15
11.	9.3734	9.3664	7.0	1.32 8.49	56.	15.9 2.47
12.	11.7357	11.7172	18.5	1.33 8.58	56.	41.8 6.5
13.	13.1210	13.1009	20.1	1.35 8.69	56.	45.2 7.0
14.	10.0183	10.0052	13.1	1.16 7.47	56.	33.7 5.2
15.	8.4027	8.3909	11.8	1.03 6.66	56.	34.4 5.3
16.	7.3745	7.3680	6.5	1.07 6.94	56.	14.3 2.2
17.	12.8598	12.8597	0.1	1.32 8.51	56.	0.23 0.04
18.	10.5393	10.5378	1.5	1.24 7.98	56.	3.6 0.56
19.	14.2800	14.2795	0.5	1.54 9.92	56.	0.97 0.15
20.	10.6393	10.6390	0.3	1.18 7.61	56.	0.76 0.12
21.	12.5377	12.5364	1.3	1.47 9.43	56.	2.65 0.41
22.	8.9851	8.9644	20.7	1.07 6.91	56.	57.8 8.99
23.	9.0787	9.0623	16.4	1.03 6.67	56.	47.7 7.4
24.	10.5782	10.5658	12.4	1.26 8.10	56.	29.5 4.57
25.	11.1250	11.1100	15.0	1.23 7.92	56.	36.6 5.68





## Plate No.10 continued

No.	Wt.be- fore	Wt.af- ter	Loss in wt. in mg.	Surface in sq.in. sq.cm.	Time in soln. hrs.	Loss in wt. in mg. per wk. sq.in. sq.cm.
26.	13.1309	13.1199	11.0	1.39	8.95	56. 23.7 3.67
27.	9.7223	9.7147	7.6	1.08	7.00	56. 21.2 3.3
28.	9.7886	9.7885	0.1	1.17	7.56	56. 0.26 0.04
29.	8.0615	8.0615	0.0	1.03	6.65	56. 0.00 0.00
30.	Too many holes.					
31.	11.0482	11.0221	26.1	1.16	7.46	56. 67.5 10.5
32.	12.1432	12.1205	22.5	1.38	8.92	56. 49.2 7.6
33.	9.7157	9.7035	12.2	1.29	8.33	56. 28.3 4.4
34.	11.5986	11.5805	18.1	1.37	8.82	56. 39.6 6.1
35.	8.8846	8.8796	14.0	1.18	7.62	56. 35.6 5.5
36.	9.6242	9.6124	11.8	1.20	7.73	56. 29.5 4.6
37.	10.8734	10.8739	-0.5	1.31	8.43	56. Small gain.
38.	9.0056	9.0057	-0.1	1.18	7.62	56. Small gain.
39.	Not prepared.					
40.	13.6999	13.6753	24.6	1.45	9.33	56. 50.8 7.9
41.	11.4792	11.4603	18.9	1.37	8.83	56. 41.4 6.4
42.	10.1712	10.1552	16.0	1.28	8.23	56. 37.5 5.8
43.	11.5339	11.5197	14.2	1.35	8.70	56. 31.5 4.9
44.	11.8143	11.8139	0.4	1.37	8.81	56. 0.9 0.14
45.	10.5319	10.5319	0.0	1.16	7.48	56. 0.0 0.0
46.	Not prepared.					
47.	Not prepared.					
48.	10.6955	10.6762	19.4	1.29	8.32	56. 44.8 7.0
49.	9.1816	9.1714	10.2	1.21	7.81	56. 25.3 3.93
50.	10.4185	10.4181	0.4	1.28	8.23	56. 0.9 0.15
51.	12.4456	12.4456	0.0	1.42	9.19	56. 0.0 0.0



Table No.10 continued

68.

No.	Wt.be- fore	Wt.af- ter	Loss in wt. in mg.	Surface sq.in.	in sq.cm.	Time soln.	in hrs.	Loss in wt. in mg. per wk. sq.in.sq.cm.
55.	9.7545	9.7544	0.1	1.38	8.89	56.		0.2 0.03
56.	8.4508	8.4506	0.2	1.14	7.33	56.		0.5 0.08
66.	2.0772	2.0769	0.3	0.57	3.66	56.		1.6 0.24

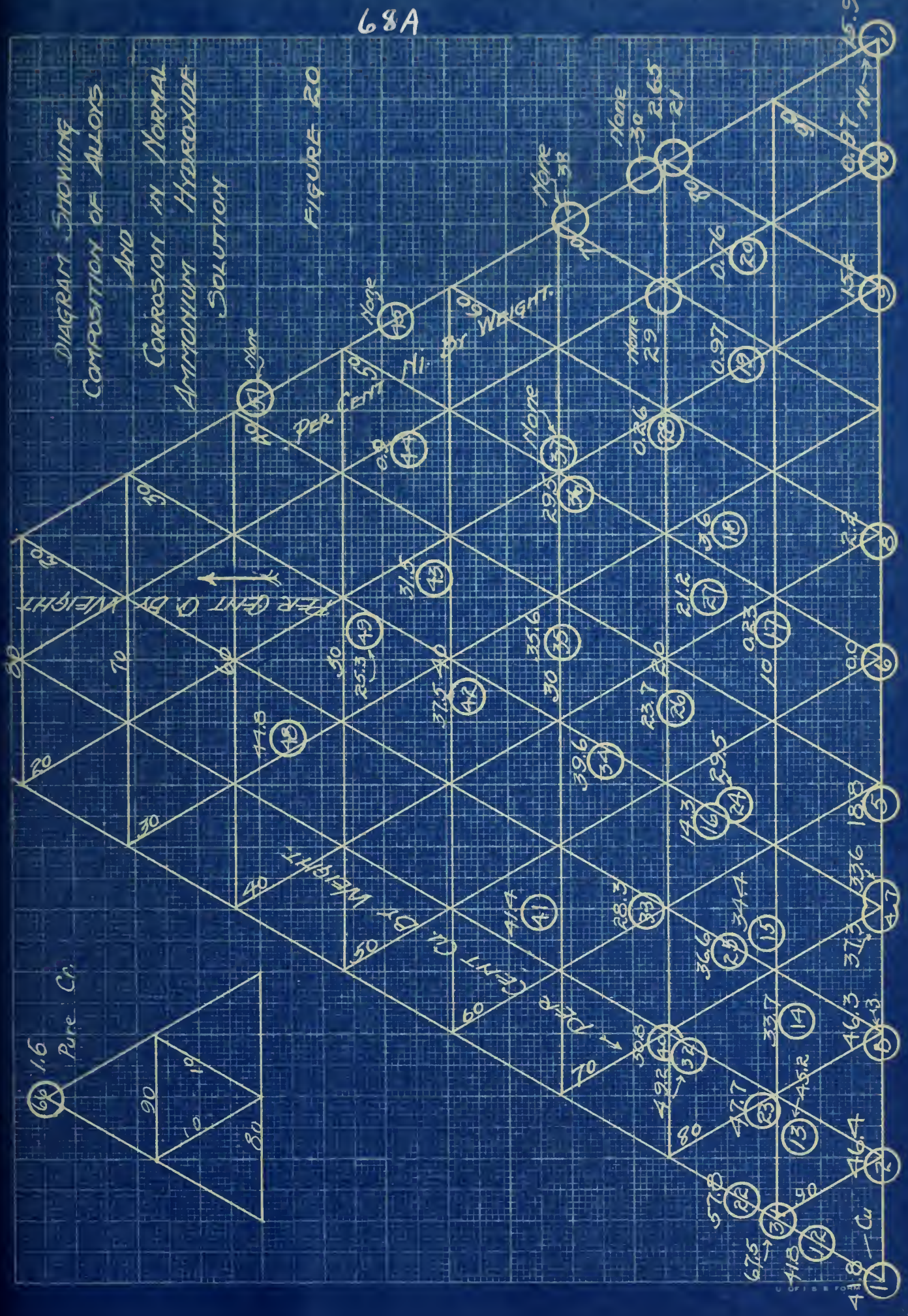






DIAGRAM SHOWING  
COMPOSITION OF ALLOYS  
AND  
CORROSION IN NORMAL  
AMMONIUM HYDROXIDE  
SOLUTION

FIGURE 20





LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS

## CORROSION IN FATTY ACIDS

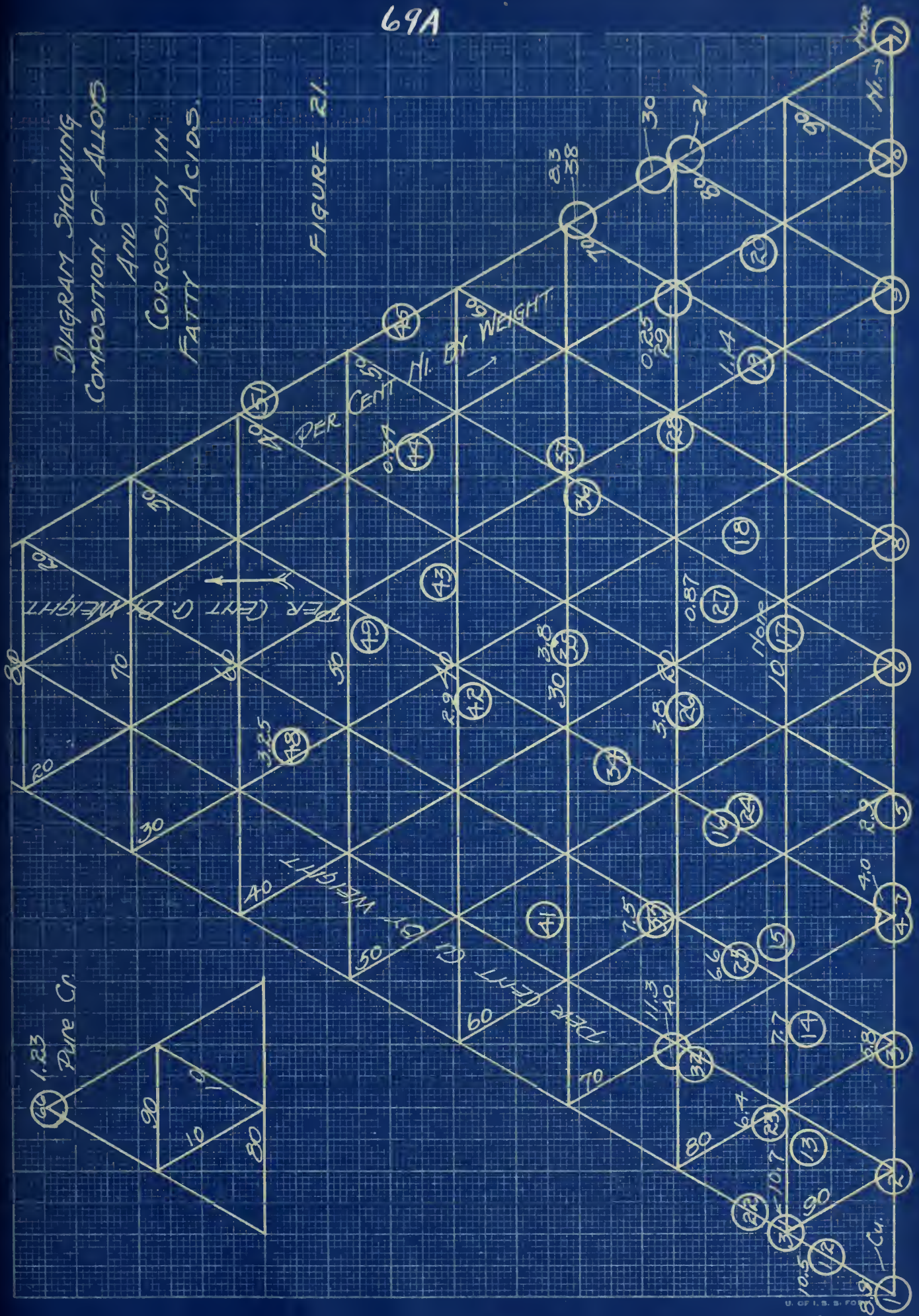
No.	Wt.be- fore	Wt.af- ter	Loss in wt. in mg.	Surface in sq.in. sq.cm.	Time in soln. hrs.	Loss in wt. in mg. per wk. sq.in. sq.cm.
(Corrosions in 100 cc. of fatty acids at 105°C.)						
1.	5.4524	5.4500	2.4	0.71	4.58	64. 8.9 1.38
3.	5.6162	5.6147	1.5	0.68	4.41	64. 5.8 0.89
5.	4.4737	4.4730	0.7	0.64	4.12	64. 2.9 0.45
7.	16.8560	16.8537	2.3	1.52	9.83	64. 4.0 0.62
11.	9.3664	9.5272	Gain due to taking up some fatty acids.			
12.	11.7172	11.7119	5.3	1.33	8.58	64. 10.5 1.62
14.	10.0052	10.0018	3.4	1.16	7.47	64. 7.7 1.20
17.	12.8597	12.8602	-0.5	1.32	8.51	64. Small gain.
23.	9.0623	9.0598	2.5	1.03	6.67	64. 6.4 0.99
25.	11.1100	11.1069	3.1	1.23	7.92	64. 6.6 1.00
26.	13.1199	13.1197	0.2	1.39	8.95	64. 3.8 0.59
29.	8.0615	8.0614	0.1	1.03	6.65	64. 0.25 0.04
(Corrosions in 200 cc. of fatty acids at 85°C.)						
19.	14.2795	14.2788	0.7	1.54	9.92	67. 1.14 0.18
31.	11.0221	11.0168	5.3	1.16	7.46	72. 10.7 1.66
33.	9.7035	9.6994	4.1	1.29	8.33	72. 7.5 1.27
35.	8.8706	8.8687	1.9	1.18	7.62	72. 3.8 0.58
38.	9.0057	9.0015	4.2	1.18	7.62	72. 8.3 1.29
40.	13.6753	13.6683	7.0	1.45	9.33	72. 11.3 1.75
42.	10.1552	10.1536	1.6	1.28	8.23	72. 2.9 0.45
44.	11.8139	11.8137	0.2	1.37	8.81	72. 0.34 0.05
48.	10.6762	10.6743	1.8	1.29	8.32	72. 3.25 0.50
27.	9.7147	9.7143	0.4	1.08	7.00	72. 0.87 0.14
50.	10.4181	10.4168	1.3	1.28	8.23	72. 2.4 0.37
66.	2.0769	2.0766	0.3	0.57	3.66	72. 1.23 0.19





DIAGRAM SHOWING  
COMPOSITION OF ALLOYS  
AND  
CORROSION IN  
FATTY ACIDS.

FIGURE 21.





LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS

## COMPARISON OF THE CORROSIONS IN THE DIFFERENT SOLUTIONS

(The values are loss in weight, in milligrams per week per square inch)

No.	N.NaCl	N.HCl	N.H <sub>2</sub> SO <sub>4</sub>	N.HNO <sub>3</sub>	N.NaOH	N.NH <sub>4</sub> OH	Fatty acids
1.	5.08	45.0	31.0	30.8	15.0	41.8	8.9
2.	4.18	20.0	19.5	41.4	5.9	46.4	
3.	1.6	34.2	18.4	27.7	None	46.3	5.8
4.	1.65	29.4	19.0	25.1	None	37.3	
5.	2.35	26.7	17.0	21.4	0.16	18.8	2.9
6.	2.37	21.2	15.1	11.4	0.16	0.0	
7.	0.78	7.1	19.3	22.4	1.1	2.2	
8.	1.71	23.0	17.4	11.4	0.13	33.6	4.0
9.	1.71	16.5	11.7	14.8	2.6	15.2	
10.	1.13	18.2	16.4	11.6	0.32	0.97	
11.	None	207.0	19.4	2270.	18.7	15.9	
12.	4.33	42.8	17.2	12.6	10.4	41.8	10.5
13.	2.55	28.6	14.9	10.4	6.6	45.2	
14.	1.89	6.3	11.9	10.8	0.26	33.7	7.7
15.	1.53	4.8	14.0	9.9	0.1	34.4	
16.	0.66	6.0	5.1	8.5	0.0	14.3	
17.	0.53	4.6	6.7	10.8	0.0	0.23	None
18.	0.71	8.2	5.3	15.1	2.6	3.6	
19.	0.63	7.3	12.3	17.2	2.7	0.97	1.14
20.	0.60	10.7	4.9	17.8	None	0.76	
21.	None	19.4	6.0	980.	2.7	2.65	
22.	4.00	38.3	14.2	13.1	9.6	57.8	
23.	3.65	29.5	14.5	16.3	5.0	47.7	6.4
24.	0.76	33.3	9.0	13.4	None	29.5	





Table No.12 continued

71.

No.	N.NaCl	N.HCl	N.H <sub>2</sub> SO <sub>4</sub>	N.HNO <sub>3</sub>	N.NaOH	N.NH <sub>4</sub> OH	Fatty acids
25.	2.13	8.2	4.1	10.5	1.2	36.6	6.6
26.	0.94	6.2	3.7	7.6	0.14	23.7	3.8
27.	0.85	18.8	9.4	6.2	None	21.2	0.87
28.	0.37	4.4	4.1	17.7	0.0	0.26	
29.	0.51	6.1	7.4	18.1	0.0	0.00	0.25
30.	Too many blow-holes.						
31.	4.60	30.3	16.4	60.3	0.86	67.5	10.7
32.	3.30	10.8	15.6	10.8	6.9	49.2	
33.	2.62	5.0	6.1	7.5	0.64	28.3	7.5
34.	1.37	6.6	5.3	4.8	0.58	39.6	
35.	1.05	12.3	9.6	4.8	0.09	35.6	3.8
36.	0.37	11.6	5.1	4.9	None	29.5	
37.		5.9	1.8	4.9	0.30	None	
38.	0.37	8.1	4.1	492.0	0.0	None	8.3
39.	Not prepared.						
40.	2.95	15.2	14.9	9.2	3.9	50.8	11.3
41.	1.84	7.5	12.4	8.3	1.1	41.4	
42.	1.67	11.5	11.0	7.3	1.0	37.5	2.9
43.	1.25	18.6	8.0	4.4	0.15	31.5	
44.	0.45	10.0	1.3	1.02	0.22	0.9	0.34
45.	0.40	21.2	2.2	0.60	0.53	0.0	
46.	Not prepared.						
47.	Not prepared.						
48.	2.45	16.2	13.2	9.7	5.7	44.8	3.25
49.	0.87	9.5	5.6	6.4	0.25	25.3	
50.	0.37	19.5	6.4	7.4	1.0	0.9	2.4
51.	0.27	31.2	0.35	0.0	0.14	0.0	



Table No.12 continued

No.	N.NaCl	N.HCl	N.H <sub>2</sub> SO <sub>4</sub>	N.HNO <sub>3</sub>	N.NaOH	H.NH <sub>4</sub> OH	Fatty acids
55.	0.33	11.9	3.7	7.7	1.0	0.2	
56.	0.27	32.2	1.3	0.35	0.44	0.5	
66.	2.00	16976.4	1.0	0.35	0.35	1.6	1.23





## VIII. MICROSCOPIC EXAMINATION.

1. General Discussion. The metallurgical microscope used in the examination of these alloys was a Leitz "Micrometallograph". For the most part apochromatic objectives were used with projection eyepieces. Many difficulties were met with in the preparation of the different alloys for microscopic study. No two alloys had exactly the same composition and it is almost equally true that no two of the alloys would give the best results by the same method of attack for polishing, etching, staining, and photographing. Thus each specimen became a research problem in itself.

2. Etching Reagents. A study of the different etching reagents, stains, etc. described in the literature, was made in an endeavor to find means of identifying the different constituents in the alloys. Some of the etching reagents which have been tested will be given below.

Ferric Chloride in Hydrochloric Acid:- This solution consisted of 1 per cent  $\text{FeCl}_3$  dissolved in 1:1 HCl. It has been found very useful. In some cases it has been necessary to dilute with one or more volumes of water because the etching was too rapid. An attempt was made to secure colorations by using a mixture of 25 cc. of this solution with 25 cc. of glycerine, 2 grams of resorcline and 50 cc. of water, but it did not seem to give better results.

Alkaline Potassium Tartrate:- This solution was prepared by dissolving 10 grams each of potassium carbonate and potassium tartrate in 80 cc. of water. It was tried on a sample containing 90 per cent Cu and 10 per cent Ni. It gave some color reaction,



but the time required was about three hours.

Picric and Nitric Acids:- This reagents was prepared by mixing 100 cc. of a saturated solution of picric acid in ethyl alcohol with 100 cc. of a 5 per cent solution of nitric acid in amyl alcohol. The etching was fairly good but the time required was about three hours.. It was tried on specimen No.2

Hydrochloric Acid and Nitrophenol:- This reagent contained 50 cc. of a saturated solution of nitrophenol in ethyl alcohol and 100 cc. of a 20 per cent solution of concentrated hydrochloric acid in amyl alcohol. It was tried on specimen No.3 and gave a distinct etching in about 2 hours. .

Picric Acid:- A saturated solution of picric acid in alcohol, such as is used for etching iron, was tried but after three hours the etching was poor.

Sodium Picrate:- This solution was composed of 50 cc. of 1:1 sodium hydroxide and 50 cc. of a saturated solution of picric acid in alcohol. The specimen remained in the reagent about four hours before a noticable etching was produced.

Tartaric Acid:- A 10 per cent solution of tartaric acid in water was found to have practically no effect on the alloys.

Iodine:- Iodine has been used as the tincture and in a solution of potassium iodide. These solutions can be used to etch the specimen in some cases, but they have more value in staining the specimen after it has been etched with some other reagent. Iodine stains copper or the copper-rich constituent so that it has a dark appearance. It has little effect on either chromium or nickel. This has been the best method for identifying the different constituents in these alloys.





Additional information regarding the etching and staining used may be had by a study of the microphotographs which will be included in Plates Nos. 1 to 16.

3. Results. Some of the results obtained from the microscopic examination have been referred to in the previous discussions. In general the data given with the microphotographs will be sufficient to explain them. The labels require some comment. If the composition of the alloy is given on the photograph it represents what was put into the charge and is in atomic per cents. If it is given below the photograph it shows the composition in weight per cents as found by analysis unless otherwise stated. Such marks as 23 H B show the number of the alloy (23), that it belongs to a series prepared by the writer and that the specimen was cut from the bottom of the casting. If T is found instead of B that means that the specimen was cut from the top of the casting.

Chromium-Nickel Alloys:- The microscopic examination of the alloys of chromium and copper seems to confirm Voss' conclusions:

First, that chromium and copper form a series of solid solutions (mixed crystals) in the alloys containing from 100 to 70 per cent of nickel. See microphotographs Nos. 11, 21, 30, and 38. In No. 38 the crystals are less distinct.

Second, that chromium and nickel form a eutectic which contains about 42 per cent of nickel. Guertler does not think that the metals form a true eutectic but he calls it a pseudoeutectic. Microphotograph No. 51 is of an alloy having approximately that of the above composition and it appears to have a eutectic-like structure. Specimen No. 56 which should contain more chromium shows what appears to be the eutectic structure and an excess of chromium. Although



alloys containing higher percentages of chromium have been prepared they have not been analyzed and microphotographs of them have not been made. The reason for this has been the difficulty of cutting proper samples from the extremely hard alloys.

Copper-Nickel Alloys:- The microphotographs of the alloys of copper and nickel agree very well with those obtained by Guertler and Tammann, especially for those obtained under similar conditions, viz., slow cooling. The alloys containing more than 80 per cent of nickel show large polyhedral crystals. Microphotographs of the pure metals and their alloys are shown in Plates Nos.1, 2, and 3.

Solubility of Chromium in Copper:- The tendency for chromium or a chromium-rich constituent to separate out in alloys of chromium and copper has been discussed somewhat. That effect may be seen in microphotographs Nos.12, 22, 31, and in those at the end of Chapter III. The chromium or chromium-rich constituent shows either in relief or as the light part of the photograph if the specimen was stained with iodine.

Effect of Nickel on the Solubility of Chromium:- The effect of the addition of nickel to alloys of chromium, copper and nickel may be studied in the microphotographs Nos.22 to 30 inclusive, in which series there is an increase in nickel and a decrease in copper. The separation of the chromium or of the chromium-rich constituent is apparent in the alloys from No.22 to No.26. Those containing larger percentages of nickel are more homogeneous and in No.29 well defined polyhedral crystals characteristic of a solid solution are shown. Similar effects will be seen if other series, such as Nos. 12 to 21 or 31 to 38, are studied. The alloys become practically homogeneous when the amount of nickel is more than three times the





amount of copper present.

Crystals in Nickel-Rich Alloys:- It must be remembered that the alloys studied were intended to have variations of 10 per cent in their different constituents, and it is not possible to say at exactly what nickel content the binary alloys begin to show well defined polyhedral crystals. From the specimens examined, it is evident that in the case of the binary alloys those which contain as much as 80 per cent of nickel show such crystals. On the other hand, the ternary alloys show them if they contain as much as 70 per cent of nickel. Of course the structures which have been obtained in these alloys represent what may be expected if the castings are slowly cooled, but they do not necessarily show what structure would be produced by quenching.



## IX. SUMMARY AND CONCLUSIONS.

1. An electric furnace of the granular carbon resistor type has been constructed which will operate on a 110 volt circuit, either A.C. or D.C., without a transformer and which when using a current of not more than 30 amperes will give temperatures as high as 1750°C.

2. Methods have been developed for making castings of alloys of chromium, copper and nickel, and 21 binary and 30 ternary alloys have been prepared. From this part of the work the following conclusions have been drawn.

(a) Castings of chromium and copper containing as much as 13 per cent of chromium can be prepared by melting the metals and pouring at about 1600°C.

(b) Chromium-copper alloys containing 6.08 per cent or more of chromium show a separation of chromium or of a chromium-rich constituent if they are cooled slowly.

(c) If equal weights of chromium and copper are heated together to a temperature well above the melting point of chromium and slowly cooled they do not form an alloy but two layers; the lower, rich in copper and the upper rich in chromium.

(d) The addition of nickel to alloys of chromium and copper tends to prevent the separation of the chromium or chromium-rich constituent and the alloys become practically homogeneous when the amount of nickel is more than three times the amount of copper present.

3. Physical and mechanical tests have been made with the following results:





(a) The specific gravity, at 25°C., of the alloys tested varied from 8.92 to 7.89 and decreased with increase of chromium.

(b) The Brinell Hardness Number varied from that of pure copper to that of tool steel and increased with increase of chromium.

(c) The modulus of elasticity of the 16 alloys tested varied from less than 15,000,000 to more than 40,000,000 pounds per square inch. Generally it increased with increase of chromium.

(d) The ultimate tensile strength of the 18 alloys tested varied from less than 10,000 to more than 50,000 pounds per square inch.

(e) The reductions and elongations were small in all cases.

(f) The stress-deformation curves are similar to those of cast iron.

4. An attempt has been made to find some relation between the relative electromotive forces obtained by placing the alloys in contact with four normal salt solution and their relative resistance to corrosion, but no such relation has been found from the experimental data obtained.

5. More than three hundred corrosion tests have been made. Results show that;

(a) The amount of corrosion is not proportional to the strength of the acid or base.

(b) A triangular system of plotting shows certain fairly well defined areas which are highly resistant to corrosion.

(c) Not only the alloys in the region approximating the composition of the alloy developed by Professor Farr are highly non-corrodible, but others have shown equally good resistance to



corrosion.

6. A microscopic study of the alloys has been made and the following agreements with earlier investigators have been found:

(a) The results agree with Voss' conclusions that chromium and copper form a series of solid solutions (mixed crystals) over the range of 100 to 70 per cent of nickel and that they form a eutectic, or, as Guertler called it, a pseudoeutectic, containing about 42 per cent of nickel.

(b) The results on the copper-nickel series agree with those of Guertler and Tammann in showing a continuous series of solid solutions.

(c) All nickel-rich alloys both binary and ternary show well defined polyhedral crystals.

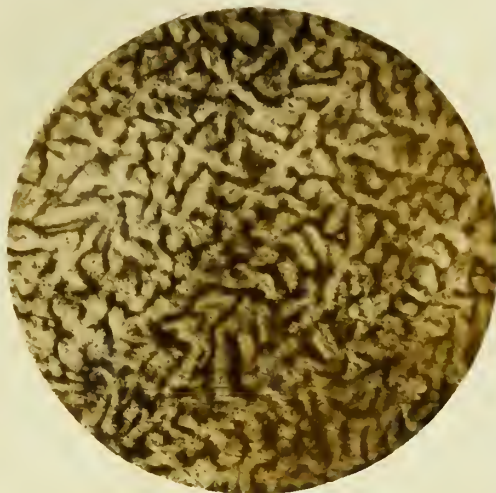




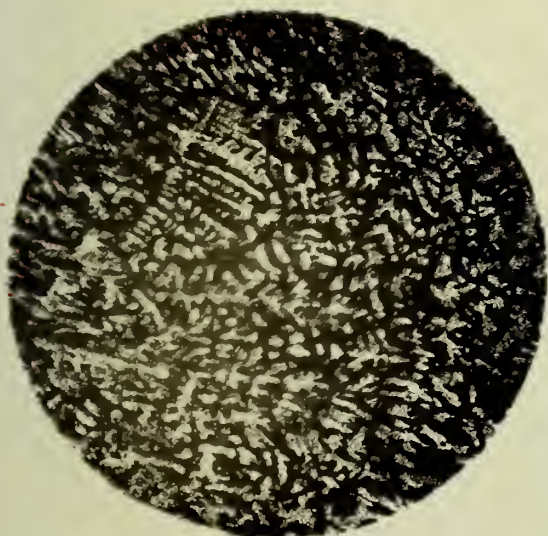
Plate No.1



No.1 x 60  
Cu 100%  
Etched in 1% FeCl<sub>3</sub> in 1:1 HCl.



No.2 x 60  
90.84% Cu, 9.06% Ni by weight  
Etched in 1% FeCl<sub>3</sub> in 1:1 HCl.



3HB  
80 Cu - 20 Ni.

No.3 x 60  
81.07% Cu, 18.76% Ni by weight  
Etched in 1% FeCl<sub>3</sub> in 1:1 HCl.



4HB  
70 Cu - 30 Ni.

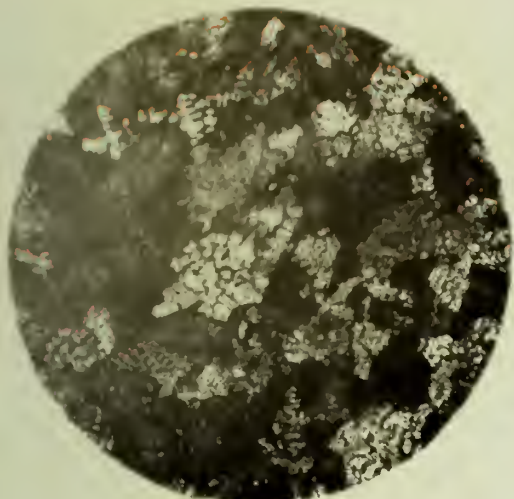
No.4 x 60  
71% Cu, 28.46% Ni by weight  
Etched in 1% FeCl<sub>3</sub> in 1:1 HCl.

LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS

LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS



Plate No.2



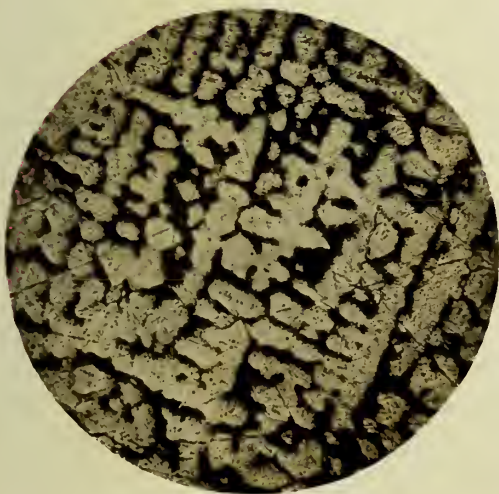
5 HB  
60 Cu - 40 Ni.

No.5 x 60  
61.63% Cu, 38.25% Ni  
Etched in 1%  $\text{FeCl}_3$  in 1:1 HCl.

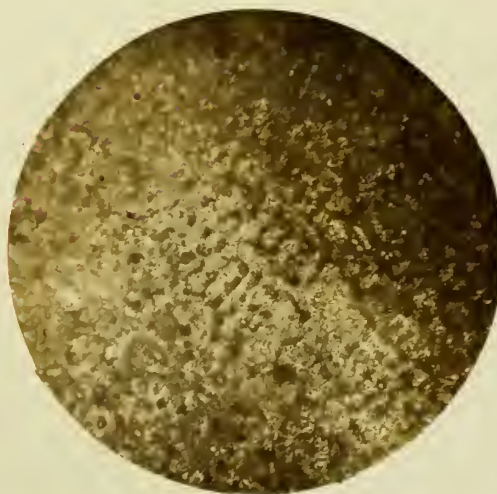


6 HB  
50 Cu - 50 Ni (By wt.).

No.6 x 60  
48.96% Cu, 49.9% Ni  
Etched in 1%  $\text{FeCl}_3$  in 1:1 HCl.



No.7 x 60  
69.13% Cu, 30.59% Ni  
Etched in 1%  $\text{FeCl}_3$  in 1:1 HCl.

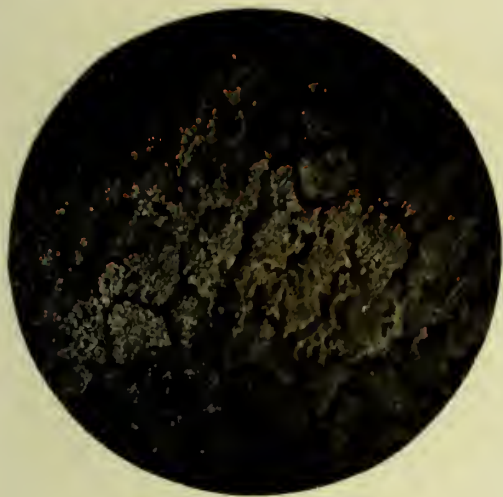


No.8 x 60  
41.14% Cu, 58.27% Ni  
Etched in 1%  $\text{FeCl}_3$  in 1:1 HCl.





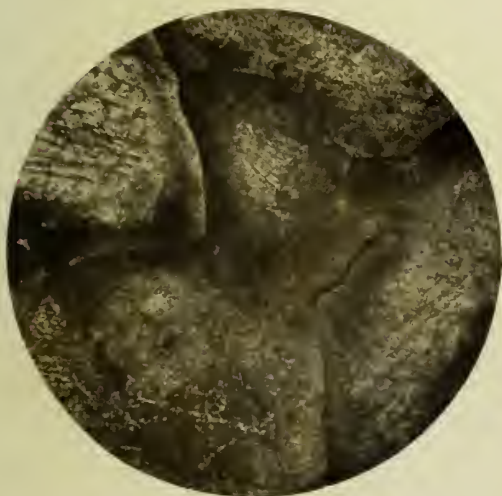
Plate No.3



No.9 x 60  
20.65% Cu, 79.35% Ni  
Etched in 1%  $\text{FeCl}_3$  in 1:1 HCl.



No.10 x 60  
10.57% Cu, 88.9% Ni  
Etched in 1%  $\text{FeCl}_3$  in 1:1 HCl.



No.11 x 60  
99.66% Ni  
Etched in 1%  $\text{FeCl}_3$  in 1:1 HCl.



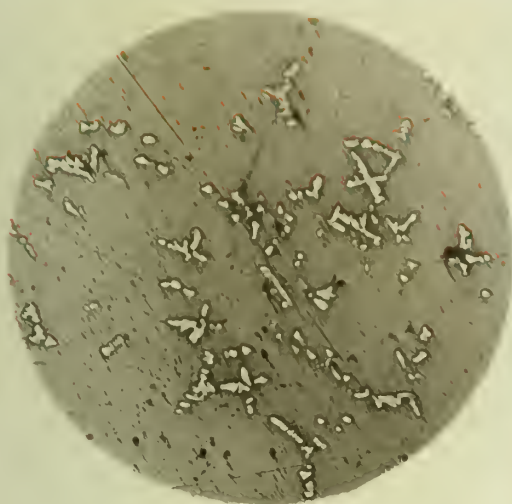
11 H.B.  
100 Ni x 15.

No.11 x 15  
99.66% Ni  
Etched in 1%  $\text{FeCl}_3$  in 1:1 HCl.

LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS

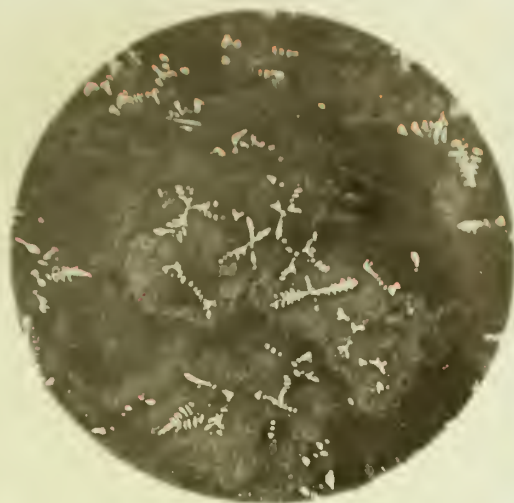
LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS





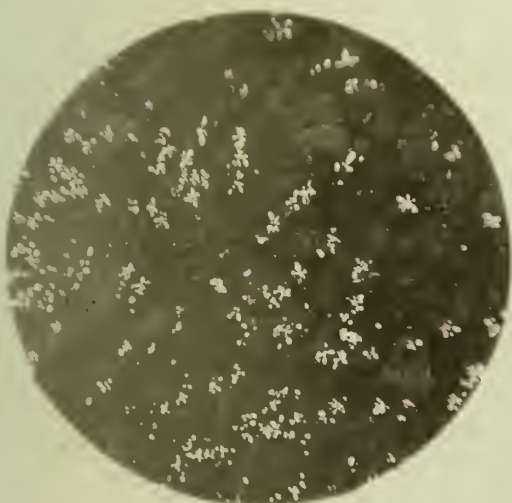
12 H.B.  
90Cu-10Cr.  
Not etched. X60.

No.12 x 60  
6.08% Cr, 94.20% Cu  
Not etched. Relief Polishing.



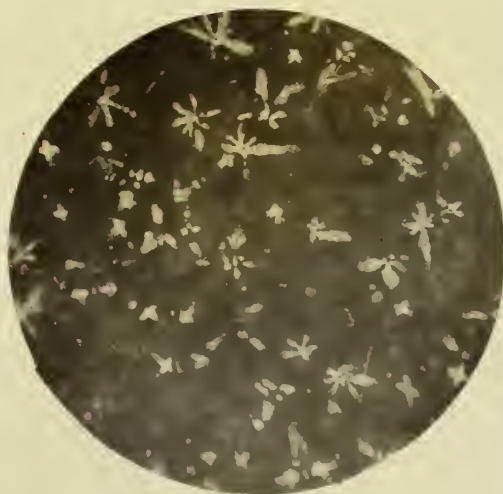
12 H.B.  
90Cu-10Cr. X60.  
Etched.

No.12 x 60  
6.08% Cr, 94.20% Cu  
Etched in 1% FeCl<sub>3</sub> in 1:1 HCl.



73 H.B.  
10Cr-80Cu-10Ni

No.13 x 60  
7.8% Cr, 84.4% Cu, 9.3% Ni  
Etched in 1% FeCl<sub>3</sub> in 1:1 HCl.



No.14 x 60  
8.3% Cr, 74.6% Cu, 16.1% Ni  
Etched in 1% FeCl<sub>3</sub> in 1:1 HCl.







No.15 x 60  
10.6% Cr, 66.3% Cu, 22.9% Ni  
Etched in 1%  $\text{FeCl}_3$  in 1:1 HCl.



No.16 x 60  
15.9% Cr, 54.7% Cu, 29.4% Ni  
Etched in 1%  $\text{FeCl}_3$  in 1:1 HCl.



No.17 x 60  
10.1% Cr, 42.6% Cu, 48% Ni  
Etched in 1%  $\text{FeCl}_3$  in 1:1 HCl.



No.18 x 60  
14% Cr, 32.7% Cu, 54.2% Ni  
Etched in 1%  $\text{FeCl}_3$  in 1:1 HCl.





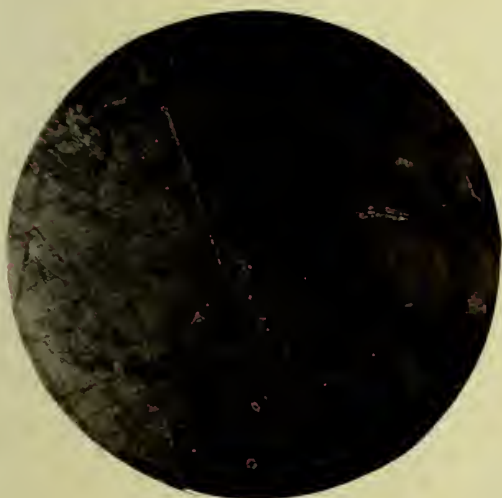
Plate No.6



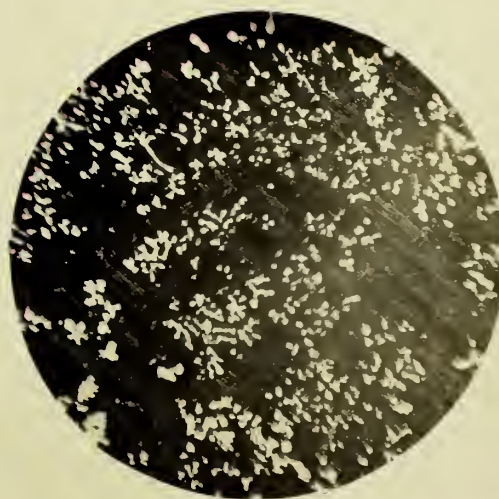
No.19 x 60  
11.8% Cr, 20.9% Cu, 66.3% Ni  
Etched in 1%  $\text{FeCl}_3$  in 1:1 HCl.



No.20 x 60  
11.9% Cr, 11.8% Cu, 76.3% Ni  
Etched in 1%  $\text{FeCl}_3$  in 1:1 HCl.



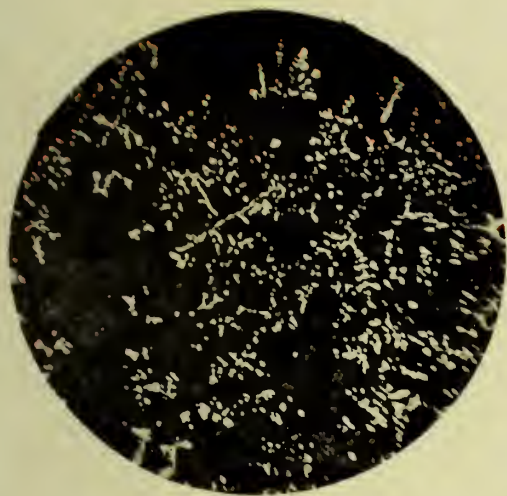
No.21 x 60  
19.4% Cr, 79% Ni  
Etched in 1%  $\text{FeCl}_3$  in 1:1 HCl.



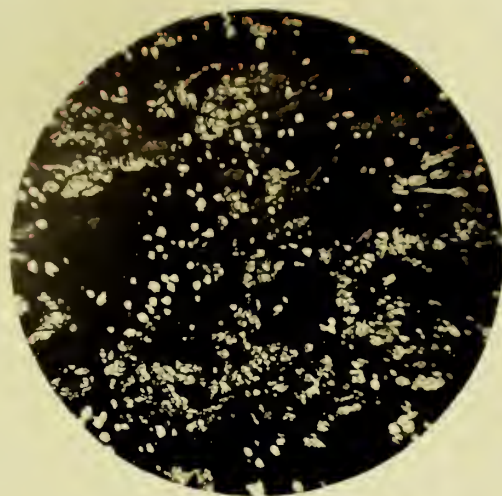
No.22 x 60  
13.2% Cr, 87.9% Cu  
Not etched. Stained in I in KI.



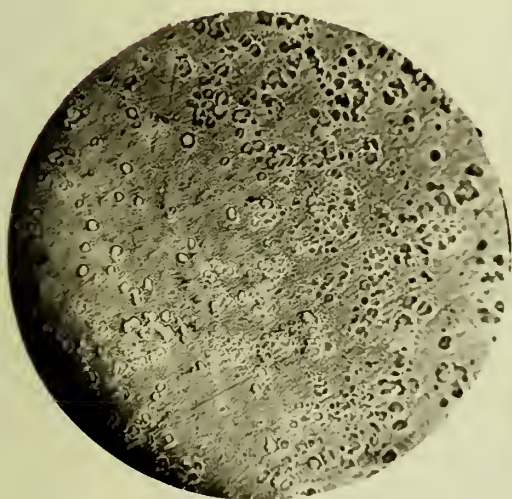




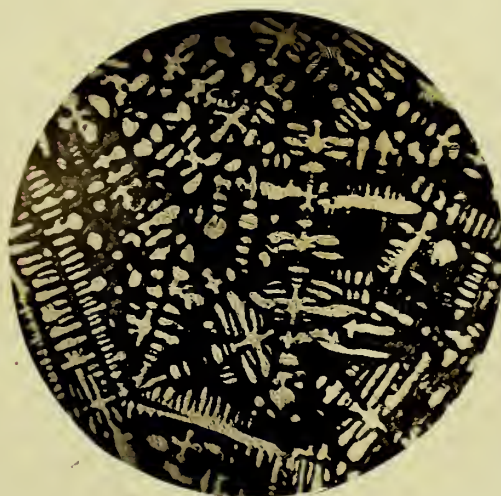
No.22 x 60  
13.2% Cr, 87.9% Cu  
Etched in 1%  $\text{FeCl}_3$  in 1:1 HCl.



No.23 x 60  
10.6% Cr, 80.6% Cu, 9.4% Ni  
Etched lightly in 1%  $\text{FeCl}_3$   
in 1:1 HCl.



23HB  
70Cu-20Cr-10Ni.  
Not etched.



No.23 x 60  
10.6% Cr, 80.6% Cu, 9.4% Ni  
Not etched. Relief Polishing.

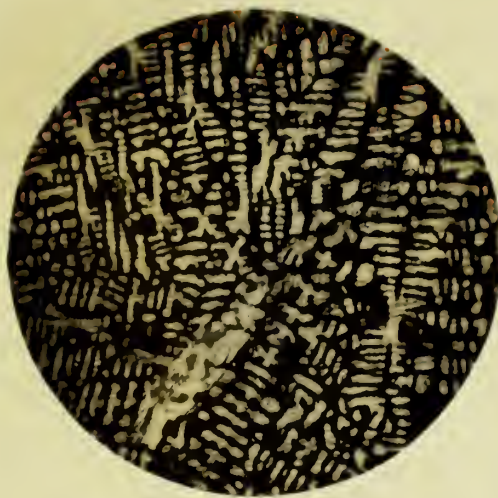
No.24 x 60  
14.6% Cr, 56.3% Cu, 29.2% Ni  
Etched and then stained in  
I in KI.



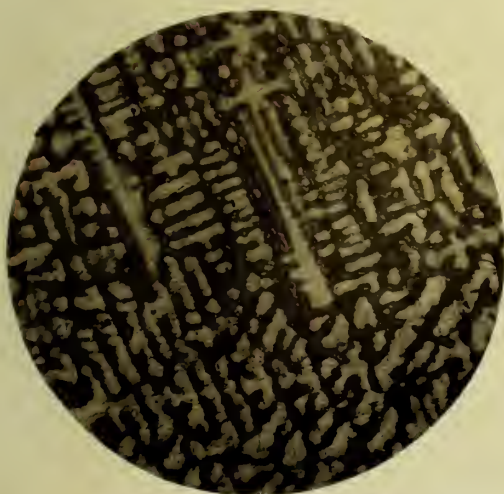




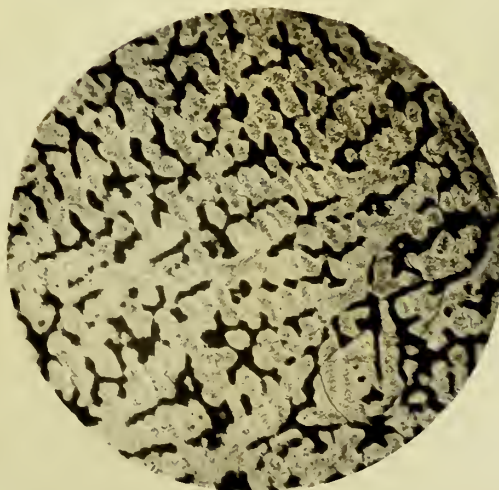
No.25 x 60  
13.6% Cr, 66.9% Cu, 19.2% Ni  
Etched and then stained in  
I in KI.



No.26 x 60  
19.3% Cr, 44.1% Cu, 36.3% Ni  
Not etched but stained in  
I in KI.



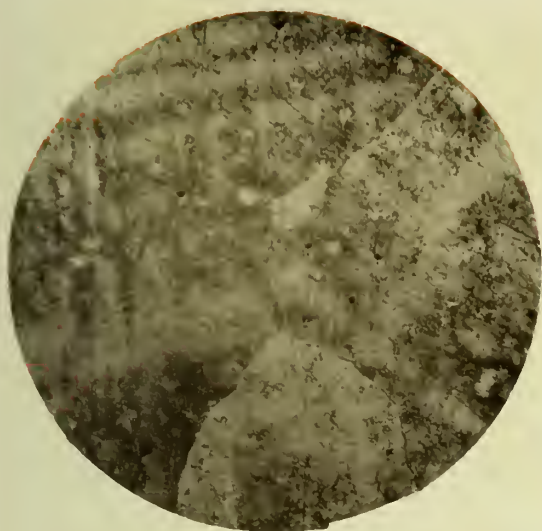
No.27 x 60  
16% Cr, 36.7% Cu, 47.3% Ni  
Stained in I in alcohol.



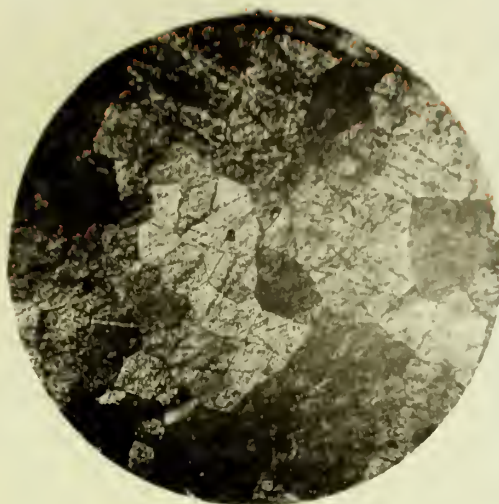
No.28 x 60  
19.9% Cr, 22.2% Cu, 57.4% Ni  
Stained in I in alcohol.





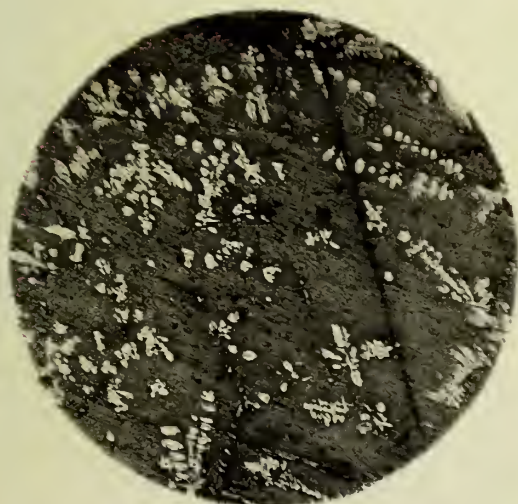


No.29 x 60  
19.6% Cr, 10.9% Cu, 68.6% Ni  
Etched in 1% FeCl<sub>3</sub> in 1:1 HCl.



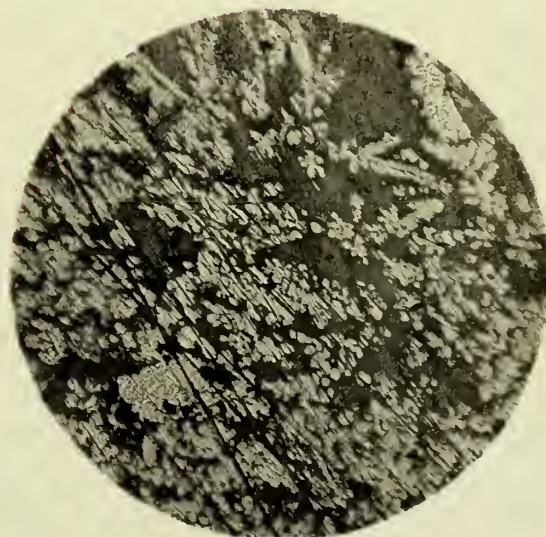
30HB  
20Cr-70Ni.

No.30 x 60  
21.5% Cr, 77% Ni  
Etched in 1% FeCl<sub>3</sub> in 1:1 HCl.



31 H.B.  
30Cr-70Cu.

No.31 x 60  
9.9% Cr, 89.9% Cu  
Not etched. Relief Polishing.

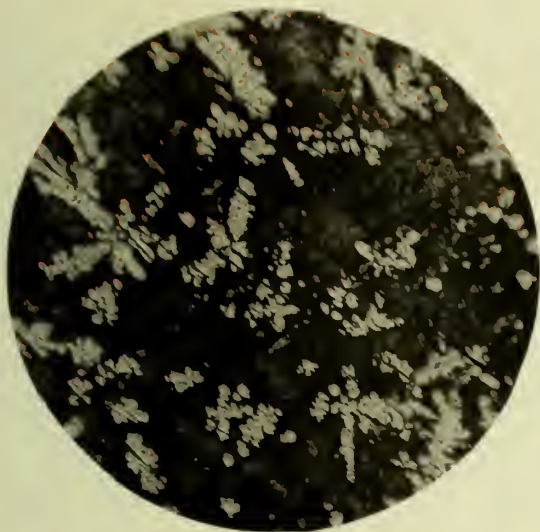


31 H.B.  
30Cr-70Cu. Not etched.  
Showing Conc. of Cr near a blow hole.

No.31 x 60  
9.9% Cr, 89.9% Cu  
Not etched. Shows concentration  
of Cr near a blow hole.







31 H.B.  
30Cr-70Cu  
Etched in I in KI.

No.31  
9.9% Cr, 89.9% Cu  
Etched in I in KI.

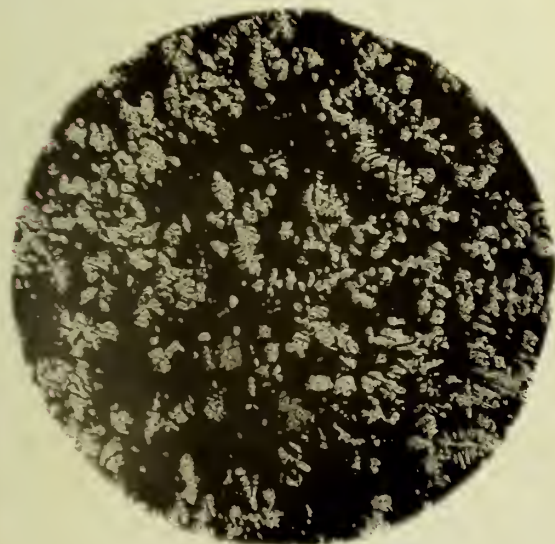
x 60



32 H.B.  
30Cr-60Cu-10Ni  
Not etched.

No.32  
17.7% Cr, 73.6% Cu, 8.0% Ni  
Not etched. Relief Polishing.

x 60



32 H.B.  
30Cr-60Cu-10Ni  
Etched in I in KI.

No.32  
17.7% Cr, 73.6% Cu, 8% Ni  
Etched in I in KI.

x 60



33 H.B.  
30Cr-50Cu-20Ni  
Not etched.

No.33  
22% Cr, 59.3% Cu, 19.5% Ni  
Not etched. Relief Polishing.

x 60



LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS

LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS



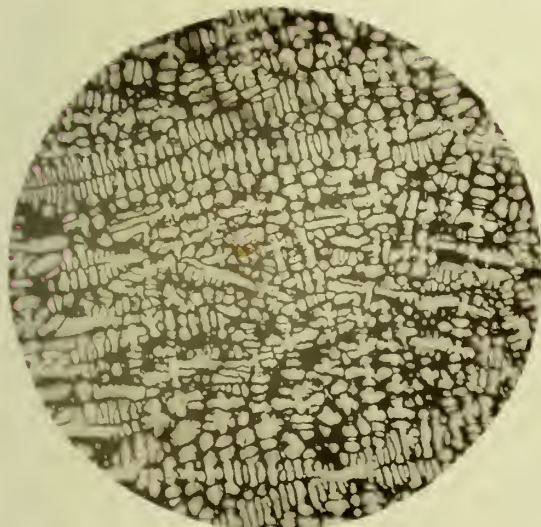
33 H.B.  
304-50Cu-10Ni.  
Etched in I in KI.

No.33 x 60  
22% Cr, 59.3% Cu, 19.5% Ni  
Etched in I in KI.



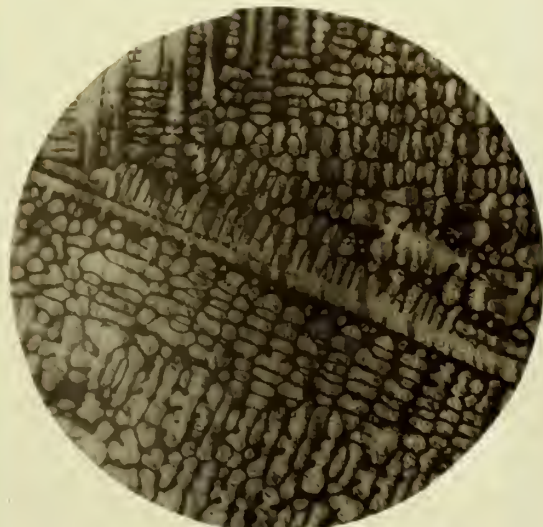
34 H.B.  
304-40Cu-30Ni.  
Etched in 1% FeCl<sub>3</sub> in 1:1 HCl.

No.34 x 60  
25.1% Cr, 45.7% Cu, 29.5% Ni  
Etched in 1% FeCl<sub>3</sub> in 1:1 HCl.



34 H.B.  
304-40Cu-30Ni.  
Re-etched in I in KI.

No.34 x 60  
25.1% Cr, 45.7% Cu, 29.5% Ni  
Etched, then stained in I in KI.

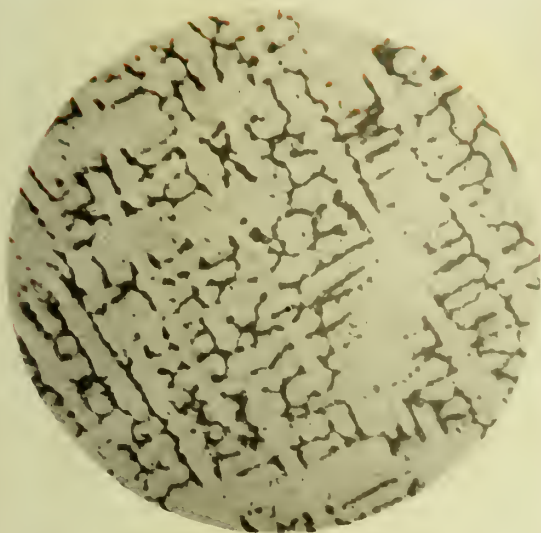


35 H.B.  
304-30Cu-40Ni.  
Re-etched in I in KI.

No.35 x 60  
29.4% Cr, 33.8% Cu, 36.8% Ni  
Etched, then stained in I in KI.

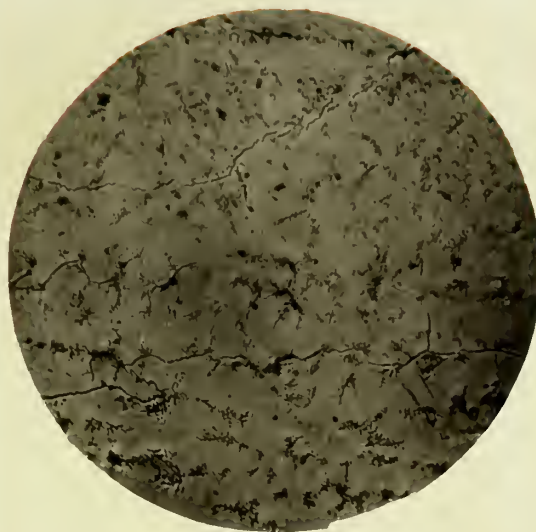






36 HB.

No.36 x 60  
28.1% Cr, 22.6% Cu, 48.4% Ni  
Etched, then stained in I in KI.



37 HB.

No.37 x 60  
29.7% Cr, 10.9% Cu, 58.1% Ni  
Etched in 1%  $\text{FeCl}_3$  in 1:1 HCl.



38 HB.

No.38 x 60  
28.4% Cr, 71.6% Ni  
Etched in 1%  $\text{FeCl}_3$  in 1:1 HCl.

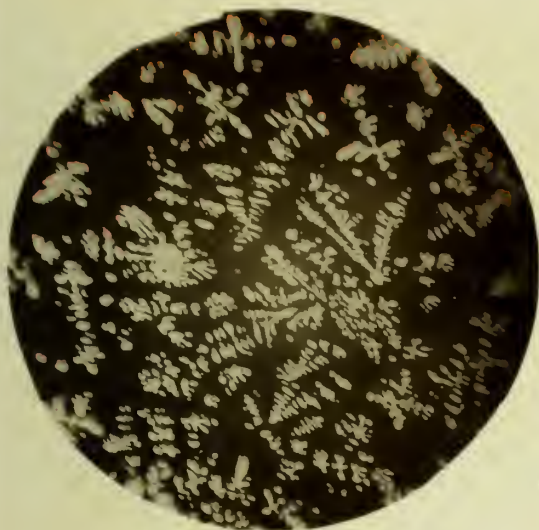


40 HB.

No.40 x 60  
19.9% Cr, 70.6% Cu, 9% Ni  
Not etched. Relief Polishing.

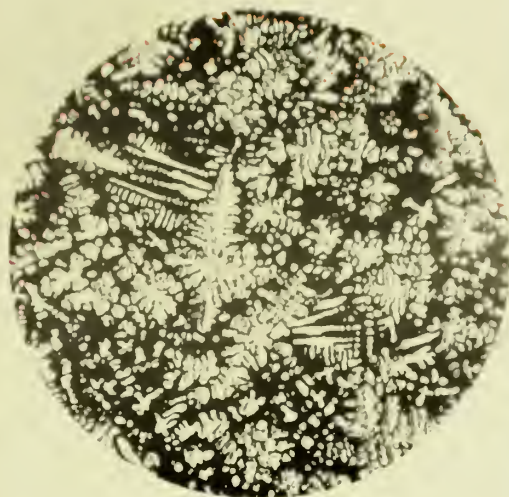






*40 H.B. Etched in I in KI*

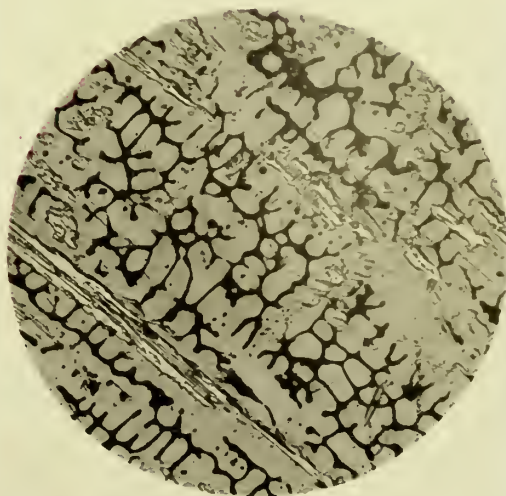
No.40 x 60  
 19.9% Cr, 70.6% Cu, 9% Ni  
 Etched in I in KI.



No.41 x 60  
 31.6% Cr, 54.2% Cu, 14.2% Ni  
 Stained in I in alcohol.



No.42 x 60  
 38.2% Cr, 33.6% Cu, 26.8% Ni  
 Etched, then stained in I  
 in alcohol.

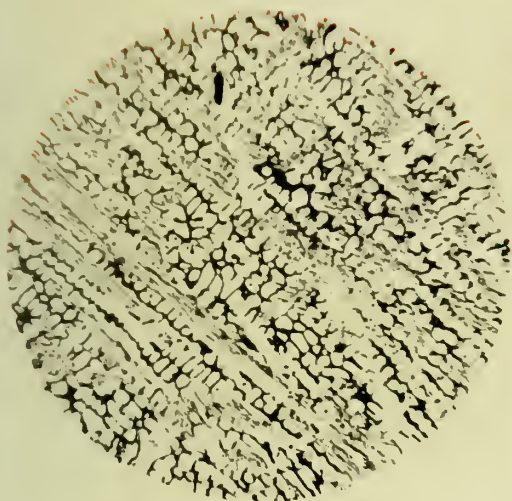


No.43 x 60  
 41.3% Cr, 22.7% Cu, 34.6% Ni  
 Etched, then stained in I  
 in alcohol.

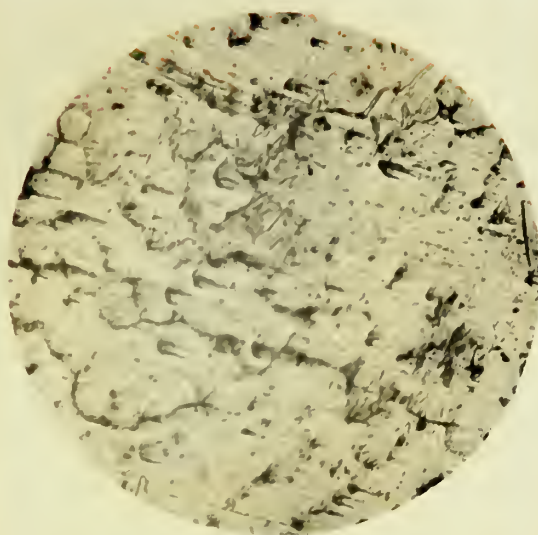




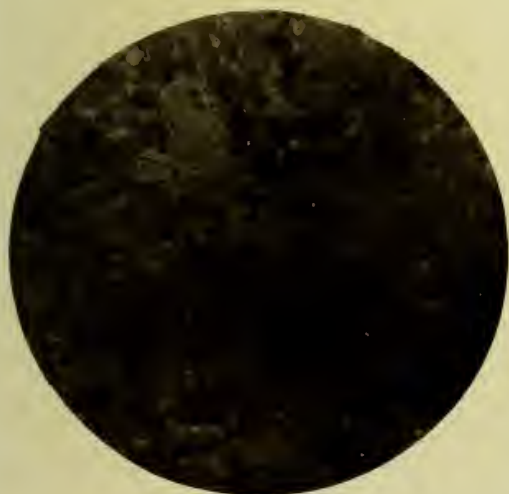
Plate No.14



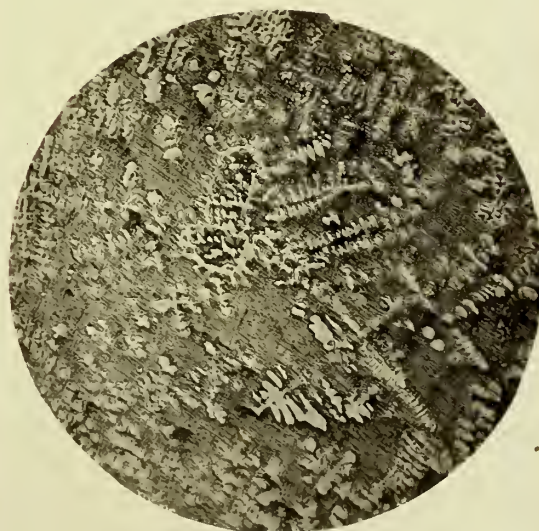
No.43 x 30  
41.3% Cr, 22.7% Cu, 34.6% Ni  
Etched, then stained in I  
in alcohol.



No.44 x 60  
43.3% Cr, 11% Cu, 46.5% Ni  
Etched, then stained in I  
in alcohol.



No.45 x 60  
44.9% Cr, 56.6% Ni  
Etched in aqua regia.

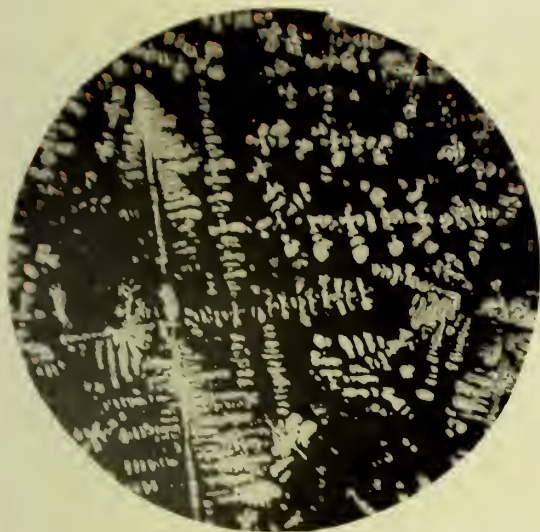


No.48 x 60  
54.9% Cr, 28.4% Cu, 17.1% Ni  
Polished, not etched or stained.

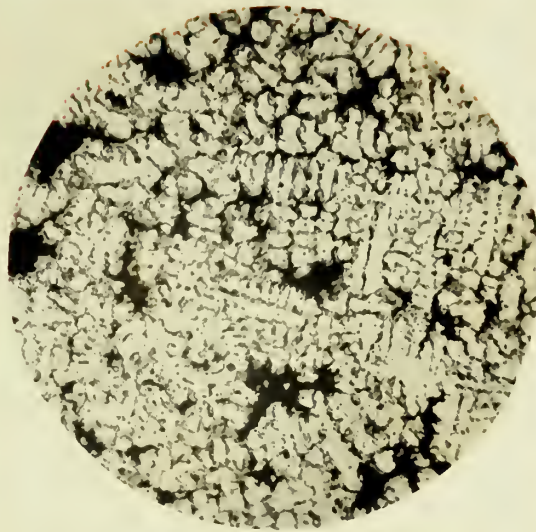


LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS

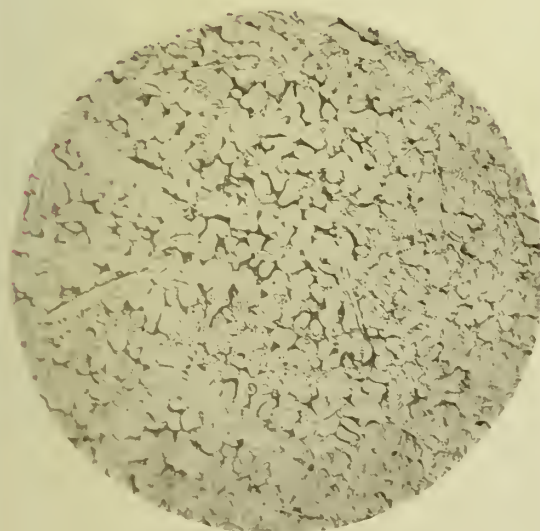
LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS



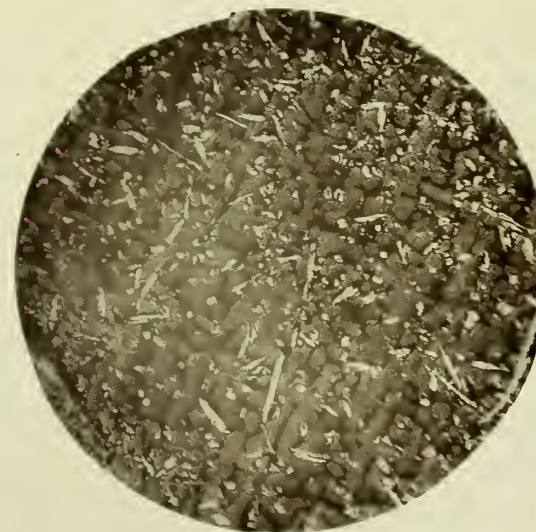
No.48 x 60  
54.9% Cr, 28.4% Cu, 17.1% Ni  
Stained in I in alcohol.



No.48 x 60  
54.9% Cr, 28.4% Cu, 17.1% Ni  
Showing concentration of Cr.



No.49 x 60  
47.5% Cr, 24.1% Cu, 26.3% Ni  
Polished, not etched.

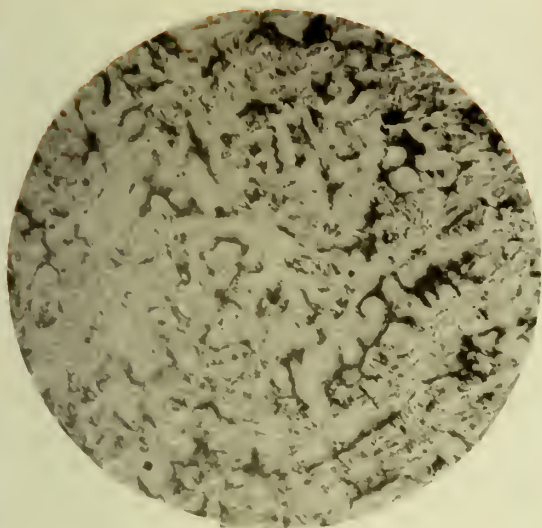


No.49 x 60  
47.5% Cr, 24.1% Cu, 26.3% Ni  
Stained in I in KI.

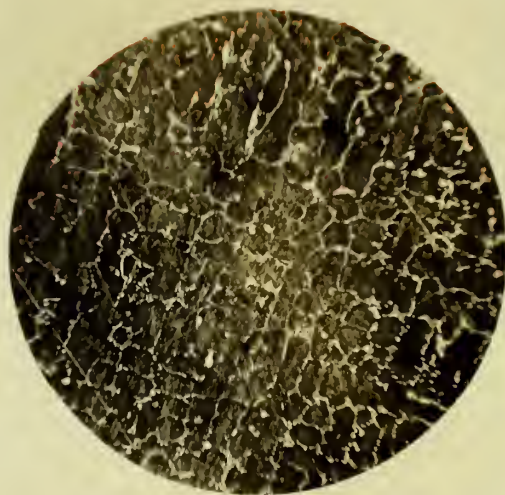
LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS

LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS





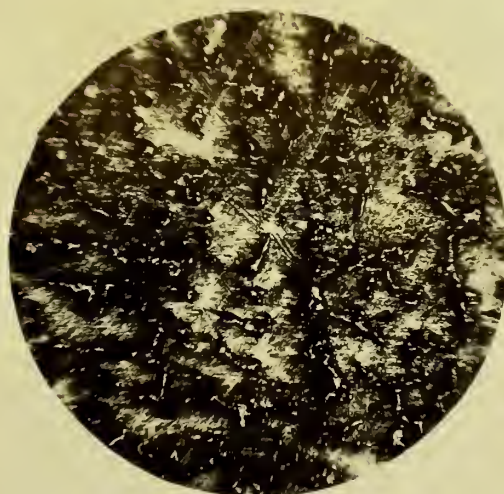
No.50 x 60  
 Approx. 46.6% Cr, 11.4% Cu, 42% Ni.  
 Stained in I in alcohol.



No.51 x 60  
 57.4% Cr, 41.7% Ni



No.55 x 60  
 Approx. 56.6% Cr, 11.5% Cu  
 31.9% Ni. Etched in aqua regia.



No.56 x 60  
 Approx. 57% Cr, 43% Ni. Etched  
 in 1%  $\text{FeCl}_3$  in 1:1 HCl, then  
 stained in I in alcohol.



LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS

LIBRARY  
OF THE  
UNIVERSITY OF ILLINOIS









